UNIVERSITY OF ALBERTA

MAPPING OF NATURALLY OCCURRING SURFICIAL PHENOMENA TO DETERMINE GROUNDWATER CONDITIONS IN TWO AREAS NEAR RED DEER, ALBERTA

A THESIS

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by

ROGER J. CLISSOLD, B.Sc.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Mapping of Naturally Occurring Surficial Phenomena to Determine Groundwater Conditions in Two Areas Near Red Deer, Alberta", submitted by Roger J. Clissold, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Groundwater mapping is the systematic examination of an area for groundwater information. A knowledge of groundwater conditions in an area is useful to hydrogeologists, groundwater hydrologists, geologists, civil engineers, agriculturalists, foresters and soil scientists. This report describes information obtained only from naturally occurring surficial phenomena studied in moderate detail over a restricted area. This method of determining groundwater conditions is judged to be most valuable in areas where no sources of groundwater information exist, and where surficial phenomena resulting from groundwater can be differentiated from those resulting from surface water.

Where the water table is a subdued replica of the topography, movement of groundwater is the result of topographic relief, modified by inhomogeneities in the permeability of the medium. Discrete discharge of groundwater in the general discharge area results from local inhomogeneties near the land surface. Systematic changes in concentration of anions and cations in groundwater occur in the direction of flow; deviations from expected changes may indicate chemical variability of the porous medium.

Groundwater mapping was done in two areas totalling 230 square kilometers. Four environments of groundwater flow (settings) were outlined from topographic maps. Each setting has a highland and adjacent gently sloping lowlands. A steep walled river valley is present in setting I and part of setting II, and dunes are present in settings II and III. Springs, seepages, hidden seepages, damp soil, vegetation, salt precipitates, soap holes, swamps, less-fertile soils, closed depressions, gullies and contorted meanders were mapped to determine or aid in the determination of relative water conditions on or near the land surface.

Four chemical types of groundwater were outlined in each area. Waters low in total dissolved solids are associated with regional or local topographic highs, and waters with high total dissolved solids are associated with regional and local lows.

The water table is close to the land surface in relatively low areas, and farther from the land surface in relatively high areas. Groundwater moving away from the land surface is associated with regional and local highlands, and adjacent to steep valley walls. Groundwater moving toward the land surface is associated with lowlands adjacent to the highlands and with local lowlands. The main flow systems in all settings originate on highlands and terminate in part on adjacent lowlands. Local flow systems are important in settings II and III, and are of minor importance in setting I.

Sixteen proposed test hole locations are outlined in the two areas. Locations were chosen with respect to 1) direction of groundwater motion; 2) chemical quality of water; 3) size of recharge area; and 4) probable distribution of rock permeabilities.

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A. GENERAL INTRODUCTION

The present study deals with the determination of groundwater conditions from naturally occurring surficial phenomena. (In this report, the term "groundwater conditions" refers to a concept encompassing the combined effects of the occurrence, the movement and the chemistry of groundwater). The primary purposes of this study are to assess the value of the mapping of groundwater conditions on the basis of naturally occurring surficial phenomena, and to determine the groundwater conditions in the areas studied.

In order that a full assessment of the method of mapping could be obtained, the areas studied were considered to be virgin lands. This meant that no specific existing hydrologic or geologic information was used. The world maps showing the distribution of climates and vegetation were referred to, as this general information would be available for studies carried out in any part of the world.

Since one of the main purposes of this study was to determine the groundwater conditions for the areas of study, only cursory attention was given to the geology and the weather. The investigation of the geology was restricted to noting the different geologic exposures and their locations. Day-to-day weather was recorded only in terms of the number of days without rain and the relative warmth of individual days.

Part B of this report contains a discussion of the principles and methods of mapping groundwater from naturally occurring surficial phenomena. The principles of mapping are, for the most part, from the literature. However, the method of mapping described was developed mainly during the present study.

Part C contains the results of the detailed study of groundwater conditions in two areas near Red Deer.

B. PRINCIPLES AND METHODS OF GROUNDWATER MAPPING

1. Introduction

Groundwater mapping can be defined as the systematic examination of a region for groundwater information. Groundwater information may be obtained from two sources: first, from man-made features used for obtaining or controlling groundwater; second, from naturally occurring surficial phenomena associated with the presence or absence of water at or immediately under the land surface within a drainage basin. The collection of information from this second source, that is, entirely from field observations, can be likened to a geologist studying an area in which only outcrops are available for interpreting the geology of the area.

This report is concerned with the second method of acquiring information. However, the principles outlined will apply in part or in whole to studies involving either method.

The study of a groundwater "outcrop" by the hydrogeologist is undertaken to obtain information which can be related to a deficiency or surplus of water at a point, relative to the water available from surface sources. A deficiency of water is interpreted as indicating that groundwater is moving away from the land surface, known as a recharge or negative potential area. (The term "negative potential" refers to the phenomenon of lower groundwater potential with increased depth below the land surface.) A surplus of water is interpreted as indicating that groundwater is moving toward the land surface, known as a discharge or, in most cases, a positive potential area (Tóth, 1966a, p. 35). At points where a deficiency or surplus is not evident, the interpretation may be that groundwater flow is parallel to the land surface; this is known as the area of parallel or hingeline flow.

The final result of groundwater mapping is the presentation of a picture of groundwater movement in an area by means of a map outlining divisions of flow away from, parallel to, and toward the land surface.

2. Principles of Groundwater Mapping

2.1. Groundwater Flow

The movement of groundwater is governed by the fluid-potential gradient. Hubbert (1940), in his classical paper "The Theory of Ground-Water Motion," showed that the movement of groundwater was from regions of higher fluid potentials to regions of lower fluid potentials. The fluid potential, which is the mechanical energy per unit mass of fluid, at a point P of the flow region is given by Hubbert's general expression

$$\phi = gz + \int_{p_o}^{p} \frac{dp}{\rho} \qquad (1)$$

where ϕ = fluid potential, g = acceleration due to the earth's gravity field, z = elevation of the point P above a standard datum, p_o = pressure of the atmosphere, p = pressure in the flow region at any point, and ρ = density of fluid. The measurement of the groundwater potential at a point in the flow region, if the point is open to atmospheric pressure, can be obtained by the expression

$$\phi = gh \qquad (2)$$

where h = elevation to which the fluid rises above standard datum("h" is often referred to as the hydraulic head). This means that the potential at a point in the groundwater flow region can be obtained from the elevation of the water level in a well open to the atmosphere times the acceleration due to gravity.

The potential field governing groundwater flow in a rigid, porous unconfined medium under natural conditions is a conservative field of force. This means that there is no change in the mass of a unit volume with time. The analysis of the potential field can therefore be made by means of the Laplace equation,

$$\nabla^2 h = 0 \qquad (3)$$

where ∇^2 is the Laplacian operator.

The configuration of the potential field results automatically in the determination

of the direction of groundwater flow. The flow will be from higher potentials to lower potentials along the lines of maximum potential gradient, that is, at right angles to lines of equal potential, provided that the permeability of the porous medium is isotropic.

Tóth (1962), using an analytic solution of the Laplace equation, derived an equation for the solution of the distribution of the potential in a mathematical model. The model was set up to simulate a small drainage basin with a linear slope in a region in which the water table is a subdued replica of the topography. Three of Tóth's conclusions are important with respect to the study of groundwater from surface phenomena:

a) The drainage basin is composed of two areas. Upslope from the hingeline (or midline) is the recharge area; downslope from the hingeline is the discharge area as shown in figure 1 (Tóth, 1962, p. 4380). The whole lower half of the drainage basin being a discharge area results in only a small portion of the groundwater being discharged in the valley bottom.

b) The belt of phreatic fluctuation is larger as the distance up the valley flank increases from the valley bottom.

c) Anomalies in the potential distribution will result from inhomogeneities of permeability in the flow region.

Tóth (1963) calculated the potential distribution in the mathematical model with a simple harmonic function, rather than a linear function, representing the valley flank. From this study the following pertinent conclusions were obtained:

a) Within a small drainage basin, three orders of flow systems can be present as shown in figure 2 (Tóth, 1963, p. 4807).

   i) first order - local system

   ii) second order - intermediate system

   iii) third order - regional system.

b) The development of local systems is a direct result of the local topography.

c) Under extensive flat areas, flow is retarded.

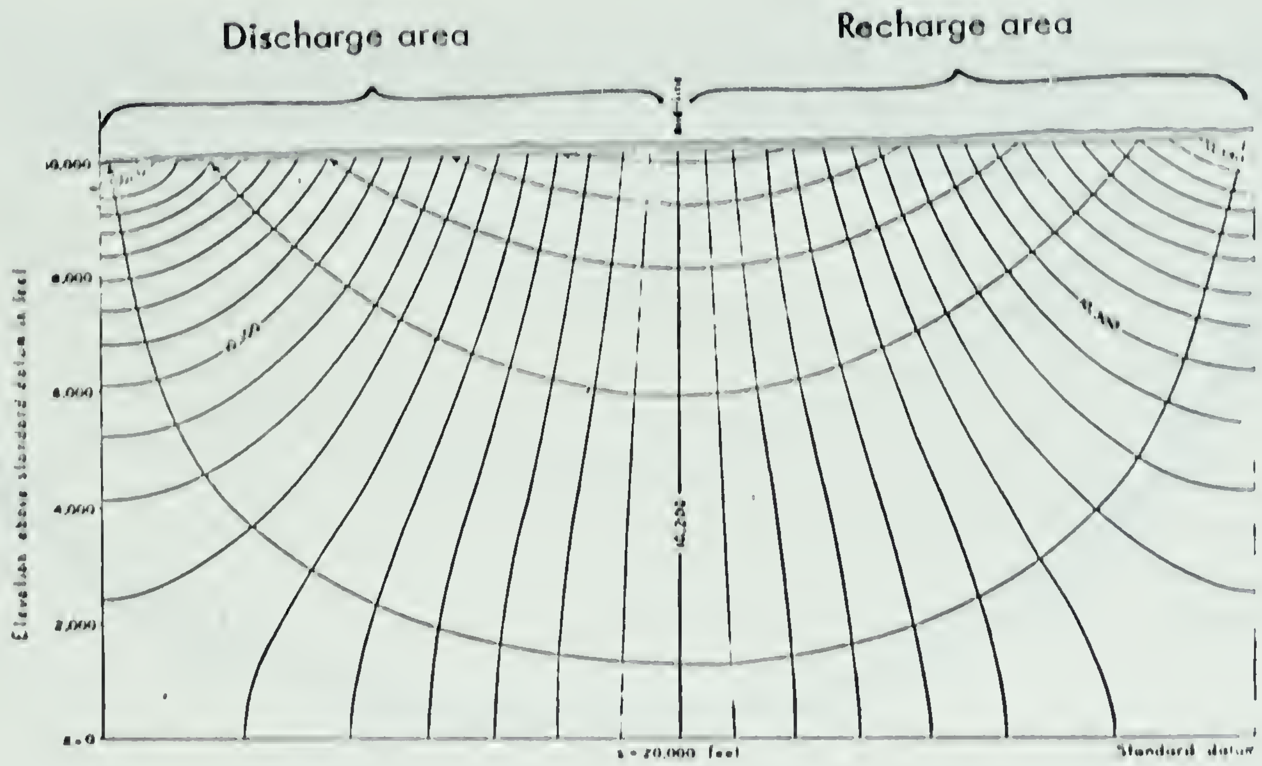

Figure 1. Distribution of recharge and discharge areas with respect to the hinge line (midline) [modified after Tóth, 1962, Fig. 3]

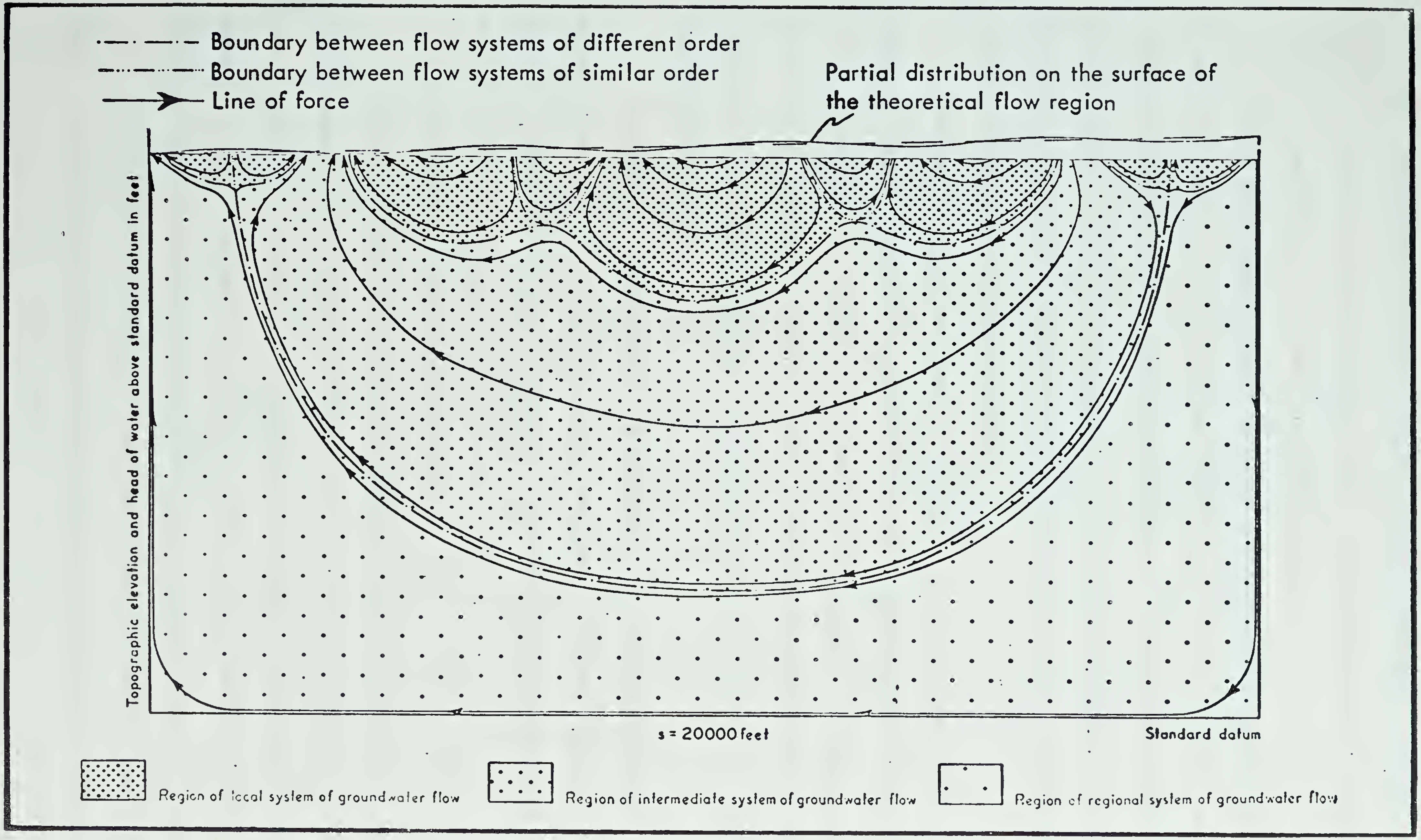

Figure 2. Theoretical flow pattern and boundaries between different flow systems [After Tóth, 1963, Fig. 3]

d) The result of local flow systems is that groundwater, from any number of adjacent local topographic highs, may be discharged in geographical proximity in one local topographic low.

Freeze (1966) used a digital computer to determine the potential distribution by numerical methods. This facilitated the calculation of flow patterns under a variety of conditions not feasible by the analytical method. The numerical method permitted the configuration of the upper boundary of the flow region to become very flexible; the inhomogeneity and anisotropicity of the flow region were not limited to simple cases; and the third dimension could be included.

The flexibility of the numerical method of analysis enabled Freeze to calculate mathematically the potential anomalies in the flow region caused by inhomogeneities in the permeability. The effect on the potential distribution of a higher permeability lens, as shown in figure 3 (Freeze, 1966, p. 149), is the same as a local topographic high; that is, on a linear surface, a recharge and a discharge area are present as a result of this situation.

In summary, the movement of groundwater is the result of topographic relief in regions where the water table follows the topography. The geology modifies the flow pattern. (Herein the reference to geology is to the change in the permeability of the rocks rather than to changes in actual rock types).

2.2 Manner of Groundwater Discharge

Each solution of the mathematical model by both Tóth and Freeze depicts groundwater moving toward the land surface in a continuous manner over the entire discharge area. However, this is not what is observed in the field. Generally, discharge is not apparent at many locations in the discharge area. At locations where discharge is observed, it occurs at discrete points rather than continuously over the entire area.

The apparent inconsistency is overcome if the mathematical model is considered again. In determining the potential distribution in a drainage basin, small areas of

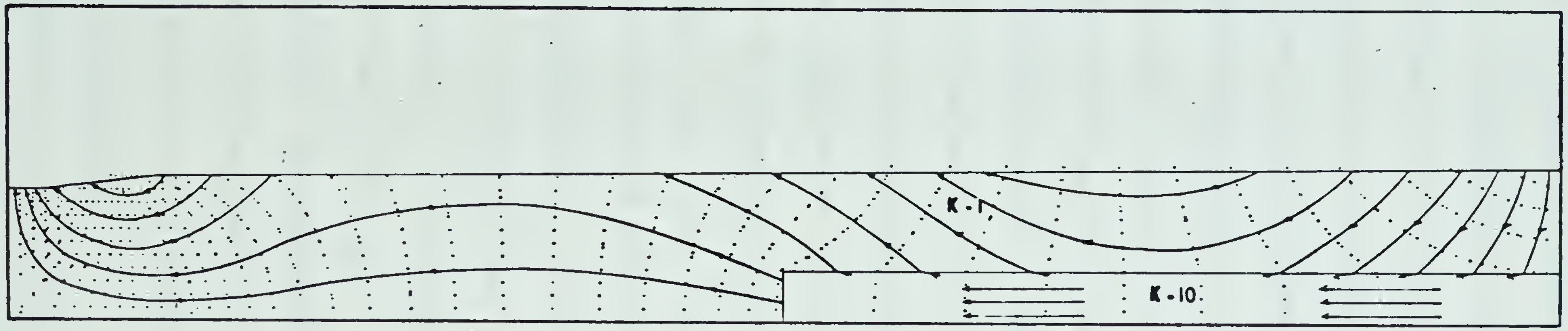

Figure 3. Flow pattern resulting from the presence of a higher permeability lens on a uniform slope [After Freeze, 1966, Fig. 20L]

inhomogeneity in the permeability (in the order of a few 10's of meters) were neglected because their effect on the potential distribution, on a scale of say, 1:50,000, is trivial. However, large areas of inhomogeneity did affect the potential distribution on the small scale. In the field though, the scale is 1:1 and, therefore, small inhomogeneities become significant. The physical laws governing the movement of groundwater are the same, regardless of the size of the inhomogeneity. Therefore, the effects are the same from either large or small inhomogeneities. Figure 4 shows the effect of a more permeable lens a few 10's of meters in length situated in a general discharge area (the dashed lines represent the equipotential lines if the lens were not present). The resulting potential distribution, given by the solid lines, is such that a point of concentrated discharge as well as a microrecharge area exist within the general discharge area. The locally distributed inhomogeneity of both rocks and soils is therefore considered to be the reason for discrete occurrences of groundwater discharge.

In those parts of the general discharge area where no discharge phenomena are apparent, three possibilities exist. First, the particular location may be a microrecharge area; second, the rate of discharge of the groundwater to the land surface may be less than the potential evapotranspiration, and consequently the water level is kept below the land surface; or third, discharge may be occurring, but may be masked by an unknown phenomenon. Therefore, the discharge area need not display at every point some phenomenon obviously related to discharge.

In short, the absence of discharge phenomena at a point does not necessarily mean that the area is not a discharge area, but the presence of discharge phenomena definitely does indicate that the area is one of discharge.

2.3 Chemistry of Groundwater

The chemical composition of groundwater varies. In the words of H. Schoeller (1962, p. 372): "La composition chimique d'une eau souterraine est quelque chose de très vivant." The chemical change in the composition of groundwater is the combined

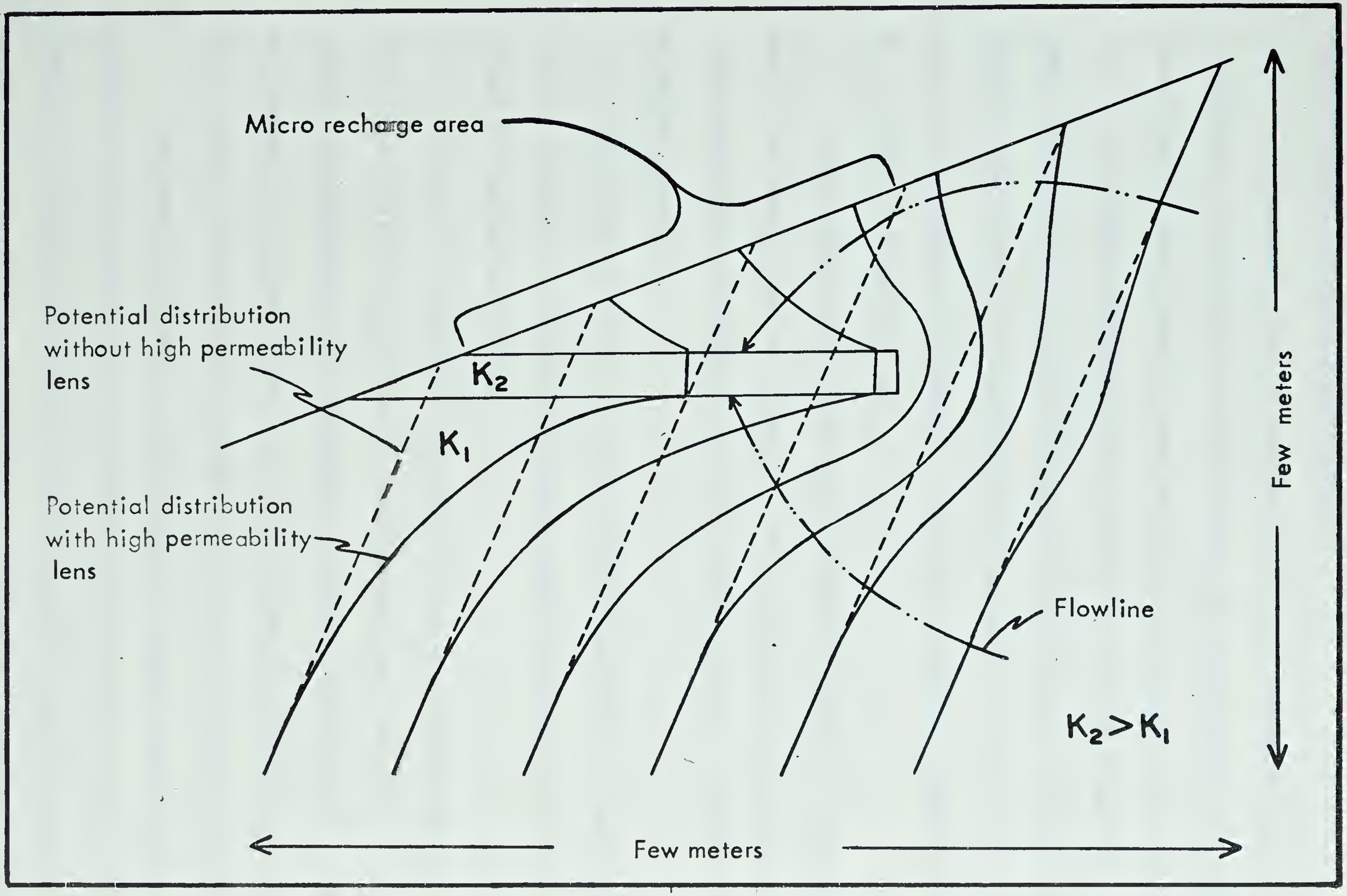

Figure 4. Diagrammatic representation of the flow pattern associated with a small high permeability lens in a general discharge area

effect of groundwater approaching equilibrium with the medium in which it is present, and groundwater being in constant motion.

Changes in the chemical composition of groundwater are due to one or more of the following: a) solution of mineral matter; b) ion exchange; c) reduction of sulphates; and d) other chemical reactions between the water and its environment.

An increase in total dissolved solids may result from evaporation, but in most cases, it is a result of continued dissolving of soluble salts. Additional dissolving of salts may result from an increased difference between the concentration of a salt in the water or may be due to the presence of a certain element or compound which increases the solubility of a particular salt.

Ion exchange, on the other hand, changes the chemical composition of groundwater by exchanging an ion in the groundwater with an ion in the medium. The most common form of ion exchange is the cation exchange (base exchange), though anion exchanges also occur.

Sulphate reduction reduces the total dissolved solids in groundwater. The hydrogen for sulphate reduction is obtained from organic compounds or molecular hydrogren through the metabolism of bacteria.

Changes in the chemical composition of the groundwater increase as the length of the flow path increases, as the rate of flow decreases, and as the size of the surface area of contact between the groundwater and the medium increases. In short, the chemical composition of groundwater is a function of the chemical and physical properties of the medium, the path of groundwater flow, and the rate of groundwater flow.

The preceding discussion of the chemical changes in groundwater is very limited. However, in some cases this may be sufficient to permit two types of information to be gleaned from an areal distribution of chemical quality, apart from the actual distribution itself. The first concerns the general movement of groundwater; the second concerns the medium through which the groundwater has travelled.

Schoeller (1962) has given the total dissolved solids, and the ratios of rSO_4* to rCl, and rCa to rMg as indicative of the direction of groundwater movement. It was shown by Schoeller that total dissolved solids will increase, and the ratios of rSO_4 to rCl and rCa to rMg will decrease in the direction of groundwater flow.

From the results of studying many groundwater analyses from all over the world, Chebotarev (1955) formulated a series of anion changes in groundwater, which correspond to the length of flow paths. The series, from recharge areas on the left with the length of flow increasing to the right, is as follows:

$$HCO_3^- \rightarrow HCO_3^- + Cl^- \rightarrow Cl^- + HCO_3^- \rightarrow Cl^- + SO_4^= \text{ (or } SO_4^= + Cl^-) \rightarrow Cl^-$$

A cation series also exists and was illustrated by Back (1960). The cation seqquence is from predominantly calcium plus magnesium waters in the recharge area to predominantly sodium plus potassium waters toward the discharge area.

The methods of Schoeller, Chebotarev and Back are ways in which the direction of groundwater movement can be interpreted from the chemical quality of water. If a series is not complete, as may often be the case, this may be indicative of a flow path which is too short to enable all the changes to take place. If, on the other hand, a deviation from the expected results occurs, an insight into the medium of flow might be obtained.

3. Method of Mapping

The method of mapping described herein is intended mainly for use in remote areas. In these areas there is assumed to be an absence of hydrogeologic information and an absence of man-made features for obtaining and controlling groundwater. However, if these sources of information are available for an area, conceivably the method discussed could still be employed as a supplement to the existing data.

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*r indicates concentrations in epm.

3.1 Map Scale

The first part of any mapping project is to determine the most suitable scale on which to work. The determination of groundwater movement, by means of naturally occurring surficial phenomena, relies on the condition of a surplus or deficiency of water at or near the land surface, relative to that which can be attributed to surface sources. To observe these conditions, it is necessary for them to be of such magnitude and intensity that they can exist over a long interval of time and can be recognized in the field. Therefore, this aspect of groundwater mapping should involve only those flow systems in which the volume of water or the rate of flow, or both, are sufficient to produce the required relative surplus and deficiency of water. In other words, the mapping of groundwater movement on the basis of naturally occurring physiographic features should not deal with the largest or smallest possible flow systems, as these will have associated with them a small volume of water exchange. Instead, the mapping should deal with the flow systems associated with the greatest percentage of groundwater exchange.

It is generally accepted that the degree to which details are examined or looked for in mapping should be commensurate with the size of the area to be mapped. Therefore, small areas need a more detailed investigation than large areas. However, if too detailed a study is made, involvement in the smallest of flow systems is inevitable. Such systems will have small volumes of circulation, and may be characterized by slow or rapid flow rates; they will be dependent upon day-to-day, or perhaps seasonal, changes in the weather. If the flow rate of a small system is rapid, the areas of recharge and discharge will be intermittent because of the small volume of total flow, and therefore, detection of these areas will be difficult if not impossible. If the areas of recharge and discharge of small systems are perennial, then the rate of flow of water will be small because small volumes of water are involved. These small changes in relative water conditions will again make it difficult, if not impossible, to detect areas of recharge and discharge, due to the effects of climate or more active systems.

Therefore, in determining groundwater movement by means of naturally occurring surficial phenomena, too detailed a study is unwarranted. For example, the determination of the movement of groundwater associated with a hill a meter* in height would not be feasible.

If an attempt is made to map groundwater features over a large area with very little detail, then detailed examination of recharge and discharge areas of smaller flow systems is not warranted. In this situation, the emphasis should be on the larger flow systems. However, when an area is extremely large, the regional gradient from the highest point to the lowest point at the top of the flow region becomes so low that the rate of flow is low. Therefore, the recharge and discharge areas of such a regional flow system will be almost if not completely masked by the recharge and discharge areas of the smaller, more active systems. Hence, the features which will be mapped belong to different local systems and no pattern of distribution will be distinguishable. Therefore, too general a coverage using this method of mapping is not advisable. For example, the determination of the movement of groundwater from the Rocky Mountains to the Gulf of Mexico would not be feasible.

From these points it can be seen that the determination of groundwater movement on the basis of naturally occurring surficial phenomena is restricted to a study which is moderate in detail over a restricted area. The detail used in mapping should be one which will permit the study of the flow systems involving the greater percentage of the groundwater exchange. The actual detail of mapping will be determined mainly by local topography, since local topography is responsible for the existence of local flow systems.

3.2 Preparatory Phase

In an area in which the water table follows the topography and for which topographic maps are available, the initial stage of investigation should be the use of topographic maps in the office.

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*1 meter = 3.281 feet = 39.37 inches = 1.09 yards.

A small-scale topographic map is needed at the onset. On the small-scale map, note should be made of regional and major topographic highs, as well as major stream channels. The distribution of major topographic features should be considered both within the area of study and in the surrounding areas. The regional slope and any major trends in the topography within the area of study should also be noted.

On larger-scale topographic maps, the area of investigation should be divided up into segments wherein similar environments of groundwater flow are present. This division into similar environments is based upon the meaning of environment, which is quantitatively describable using three parameters, namely, topography, geology, and climate.

One criterion for similarity of environments is that they have uniform climate. This condition is satisfied by either an individual area of study being small enough, or by dividing a larger area into smaller areas wherein the climate is uniform. If the geology is also uniform, then for an area to have a similar environment of groundwater flow throughout, it is only necessary that the topography be similar throughout, perpendicular to the line of maximum gradient. This latter condition is satisfied if the distribution and areal extent of corresponding topographic expressions of the same relative magnitude are more or less constant and the corresponding forms occur in the same relative position within the drainage basin.

In the situation in which the geology is not uniform throughout, it is still possible to analyse the environment of groundwater flow on the basis of topography alone. This condition presupposes that while the over-all geology is not uniform, the relative position of the rocks of similar permeability is the same in all parts of the area of similar topography and the rocks have approximately the same areal extent and thickness.

Geomorphic principles indicate a strong relationship between the permeability of rock types and subsequent land forms. For this reason, the latter set of conditions will probably suffice in the majority of circumstances.

The delineation of different areas in which the environment of groundwater flow is similar should be follwed by a study of the different types of local topographic expressions present within each area. The local topography should then be studied with respect to its position in the drainage basin and its areal extent.

The division of an area into discrete parts of similar groundwater flow permits a rough estimate of the types of flow systems expected to commence or terminate within any particular part.

In the absence of topographic maps, aerial photographs may be used to complete this part of a study. However, the interpretation may not be as fruitful as with topographic maps unless the observer is well versed in the use of aerial photographs.

This method of outlining similar environments of groundwater flow for the purpose of analogy can be likened to the initial stages of a geologic study. In this case, the geologist, by examining the topographic map, attempts to delineate areas of major geologic structures and rock types before going into the field.

3.3 Reconnaissance Phase

The first part of the field work should be a cursory traverse over the entire area. This enables the hydrogeologist to become familar with the area and also to check to see if the areas of similar environment of groundwater flow, as outlined in the office, are realistic.

The second part of the reconnaissance survey should consist of a second, fairly rapid traverse across the whole area, but this time, each similar environment of groundwater flow should be considered separately. On this traverse, an idea of the more obvious features associated with recharge and discharge areas should be obtained. This includes both their distribution and their density.

To obtain the best indication of the distribution of features on the reconnaissance survey, it is desirable to traverse along a line essentially parallel to the flowlines. A traverse parallel to the flowlines can most closely be approximated by

following a line of maximum gradient of the topography. The traverse should either commence on the topographic high and terminate towards the valley bottom, or vice versa.

The reconnaissance survey should provide an outline, by which the detailed investigation is to be carried out. The outline should include the order in which individual environments of groundwater flow are to be mapped, when only the natural movement of groundwater is considered.

3.4. Detailed Investigation

The purpose of a detailed investigation is to obtain groundwater information from flow systems involving the major part of groundwater exchange. The information collected from naturally occurring surficial phenomena is related to whether or not there is a surplus or a deficiency of water at a point, relative to that which could be attributed to surface sources. The possibilities are the following: a definite surplus; a definite deficiency; a possible surplus; a possible deficiency; or no indication of either a surplus or a deficiency.

A definite surplus of water is indicated in three possible ways: a discharge of groundwater upon the surface of the lithosphere, as in the case of a spring or a seepage; the development of phenomena related to the discharge of groundwater, without the water actually being observed (for example, the presence of salt precipitates); or the observation of quasi-stable water levels either on or immediately below the land surface.

A definite deficiency of water is difficult to observe. However, one indication of a deficiency is obtained from "dry depressions" (Tóth, 1966b). These depressions lack the characteristic features associated with depressions which contain water for a duration sufficiently long enough to develop features characteristic of wet conditions. The two factors believed to be responsible for this condition are the quick infiltration of collected surface waters and the lack of groundwater being discharged into the depression. Therefore, these depressions are interpreted

as being locations of a definite deficiency of water.

If there is an absence of features related to a relative surplus or deficiency at a location, the point can be omitted. The reverse case in not true; that is, when the interpretation could indicate either a surplus or a deficiency. In this case then, if there is no indication after all possibilities are considered, the best procedure is to record the location as questionable, and to see how it is related to phenomena in the adjacent area.

An example of this latter condition might be given by a depression which contains water. There are three possibilities for the water being in the depression: first, that the surface water is prevented from infiltrating by an impermeable bottom; second, that the water cannot infiltrate because the groundwater potential below the land surface increases with depth due to the depression being in a discharge area; third, that there is a slow discharge of groundwater maintaining water in the depression.

Adding to the uncertainties of the interpretation of relative water conditions, there are locations which, because of their position in the basin, are local points of surplus water for a part of the year, and points of a deficiency of water for the remainder of the year. This type of situation was encountered by Meyboom (1966) in the Allen Hills, Saskatchewan.

At any observation point, it is necessary to collect information of two basic types, namely, descriptive and measured. The descriptive data refer to the presence, absence, type, and interrelation of individual phenomena present at an observation point. This will include the presence or absence of water, type and distribution of vegetation, and land forms, both local and general. The measured data consist of information to which a certain value is assigned. This will include rates of discharge of water, chemical and physical properties of water, and elevation of the observation point.

The data are obtained from field traverses, topographic maps and aerial photographs. Field traverses provide most of the measured and descriptive data. Both topographic maps and aerial photographs provide a small amount of descriptive data. Aerial photographs, besides being used to obtain basic data, are also valuable in the determination of variations in the physiography of the area. This variation in the physiography helps to determine the route of field traverses.

The density of field traverses is determined by the topography, as was noted earlier. On each traverse, points or areas are visited which are either outlined from the aerial photographs or are encountered on a field traverse. At each observation point visited, the location should be described, and any measurable data should be collected. At locations where the water conditions are definitely determinable, note should be made of accompanying features in order that at other locations where the obvious criteria are absent, some inference can be made as to the possible water conditions at the location or in the immediate vicinity.

The group of phenomena which depict a deficiency or a surplus of water will vary from area to area. However, once a group of phenomena have been related to a relative surplus or deficiency of water in a particular area, then the phenomena of the group will be able to be used over a relatively large region, with only slight modifications.

3.5 The Presentation of Final Results and Conclusions

The presentation of results is by means of maps, tables, and diagrams. For the most part, these are common or straightforward methods with the purpose of determining and representing the chemical quality of water at or near the land surface and the relative water conditions over the area of study.

The interpretation of groundwater movement is made from the distribution of the relative water conditions. Areas with a deficiency of water at or near the land surface are interpreted as being areas in which the water is moving away from the land surface in the zone of saturation. These are termed recharge areas. This

means that the groundwater potential will decrease with increased downward distance from the land surface in the flow system present. Areas with a relative surplus of water are interpreted as indicating that the water is moving towards the land surface. These are called discharge areas. Discharge areas have an increase in groundwater potential, within the flow system present, as the distance downward from the land surface increases along a line perpedicular to the plane of the land surface. The map of recharge and discharge areas then outlines the regions in which groundwater is moving away from or toward the land surface. The distribution of these areas on the land surface provides a means of estimating the potential distribution of groundwater at depth by employing a mathemiatical model, or analog-simulation model. The mapping serves as a form into which the model is fitted.

The variables of the model employed are manipulated until a recharge and discharge pattern, similar to that observed in the field, is obtained. From the model the distribution of the fluid potential in a vertical plane is approximated. A good indication of groundwater movement in an area is obtained from the combination of potential distribution in the horizontal, from the water-level map and, in a vertical section, from the model.

4. Utilization of Conclusions in Various Disciplines

A knowledge of the movement of groundwater in an area is of great importance to many disciplines. However, in many cases, a complete reliance on naturally occurring surficial features for the reconstruction of the flow pattern is an academic approach. The absence of existing hydrologic data is a reality in many areas, but a great deal can be gleaned from the already existing man-made features.

In uninhabited or sparsely inhabited regions though, the mapping of naturally occurring phenomena may be the only reasonable way to determine groundwater movement. Therefore, mapping can be used to infer groundwater possibilities in areas of anticipated development which at present are uninhabited. The method

is also useful when it is desirable to estimate the total water potential of an uninhabited area.

In other disciplines, a knowledge of the movement of groundwater in sparsely populated areas is also conceivably useful. In geology, for example, this knowledge could lead in some cases to a more fruitful exploration project for mineral accumulations. Engineers, dealing with problems of waste disposal, must know the path of groundwater flow before determining if, and where, wastes can be discharged into the lithosphere. Other disciplines, for example, agriculture, forestrey, or soil science, may be only interested in one particular aspect of the mapping results such as the surface distribution of the areas of upward and downward flow, or perhaps the chemical types of water and their distribution in the discharge area.

C. APPLICATION OF THE MAPPING METHOD TO TWO AREAS NEAR RED DEER

1. Introduction

1.1 Purpose, Scope and Techniques

The present project has a twofold purpose: first, to assess the value of field-mapping of groundwater from naturally occurring surficial phenomena alone, both as a method of groundwater exploration and as a method for use in other aspects of science; and second, to provide a basis for a test-drilling project concerned with the development of a public water supply from the area studied.

The area of the present study was selected so that the results of the second purpose could be utilized in the foreseeable future, in order to evaluate fully the conclusions of this study. A test-drilling program in the Red Deer area for a supply of groundwater for the city of Red Deer was scheduled to commence in 1966. When this investigation was delayed until 1967, the area became an ideal choice for the present study.

In order that the proposed aims of this report be realized, it is necessary to consider five phases of study, which are as follows:

a) The mapping of naturally occurring surficial phenomena throughout the area of study;

b) A detailed investigation of pertinent phenomena;

c) A study of the areal distribution of the different chemical types of water as determined from water samples collected at or immediately below the land surface;

d) The distribution of areas of groundwater moving towards the land surface and areas of groundwater moving away from the land surface;

e) The inference of groundwater motion within the area of study.

The study of the area included traverses by automobile and on foot. Areas adjacent to the road were observed on traverses which were conducted in the automobile, while traverses on foot were made across the fields. The information was

obtained almost completely from naturally occurring surficial features. At some locations, additional information was obtained by augering a 4-centimeter diameter hole to shallow depths (the auger can be observed in Plate IXA). Water samples were collected only at points where water was present on or near the surface. Water samples from near the surface were obtained from auger holes by means of a plastic tube. Chemical analysis of the water samples was carried out partly by field methods and partly by laboratory methods.

1.2 General Description of the Area

The present study in the vicinity of Red Deer is confined to two separate areas (Fig. 5). The east area is contained within latitudes 52° 10' N and 52° 20'N and longitudes 113° 40' W and 113° 55' W. The west area covers most of the area between latitudes 52° 05' N and 52° 15'N and between longitudes 114° 00'W and 114° 20' W. Each area comprises approximately 115 square kilometers (45 square miles).

Both areas occur in the "Coniferous Forest" vegetative zone, close to the boundary with the "Prairie Grasslands" zone, on the maps of the world distribution of vegetation (Trewartha, 1954).

According to the Köppen classification (Trewartha, 1954), the areas studied lie in the Dfc climatic zone (cold climate, short cool summers with humid winters), close to the BSkw climatic zone (mid-latitude steppe climate).

Situated east of the Canadian Rockies and west of the flat prairies, the areas have a moderate relief. The high lands, which are in the form of a digitated ridge in the east area, and a broad elongate ridge in the west area, are composed mainly of sandstone with shale lenses (Plate I). A thin veneer of glacial drift covers most of the higher land.

The lower-lying, relatively even-sloped land is covered with an assortment of ground moraine, lacustrine and aeolian deposits. Preglacial gravels are exposed

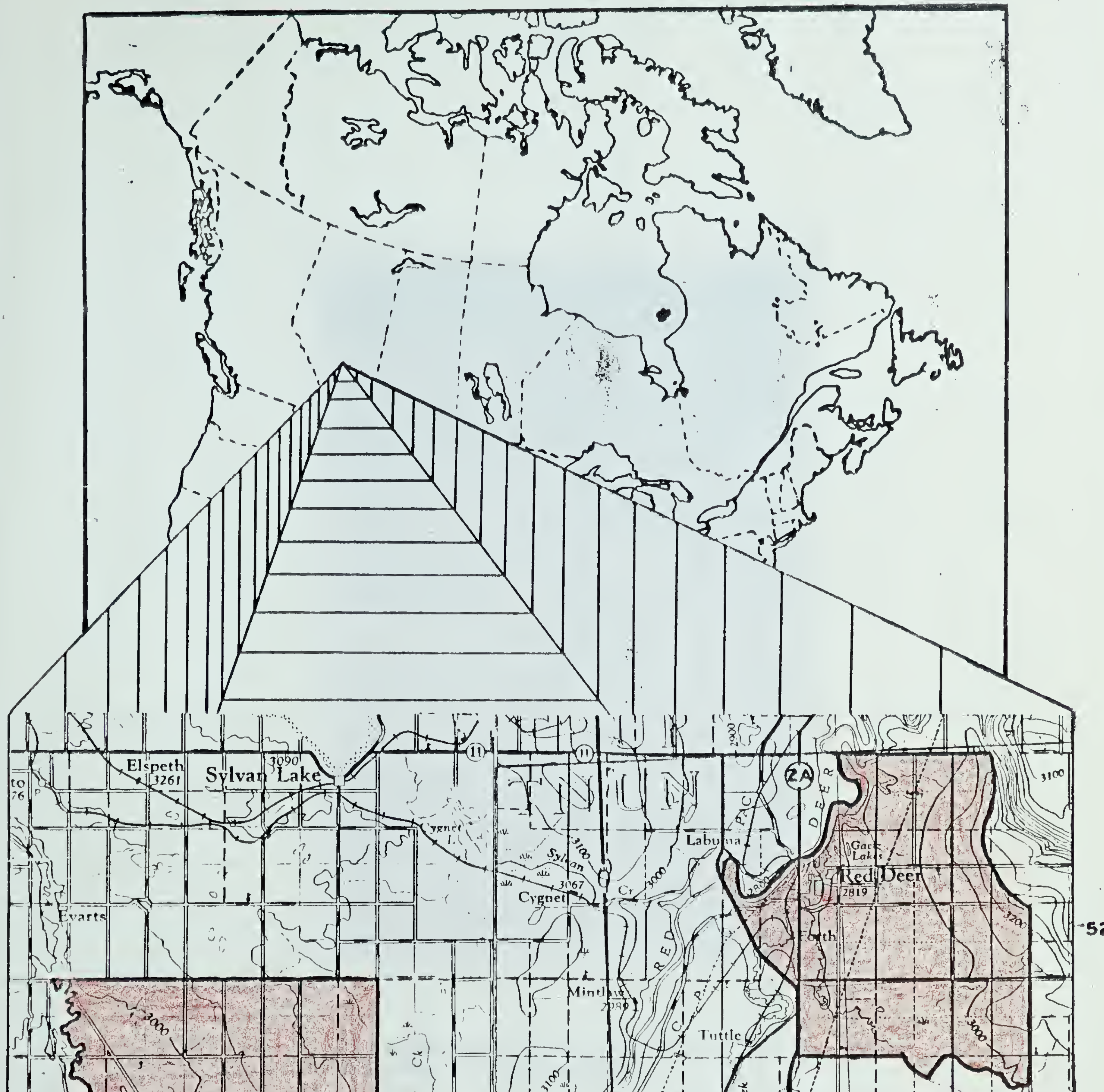

Figure 5. Location of the two areas of study.

Photograph of an outcrop showing rock types associated with the highlands.

PLATE I

in the bank of the Red Deer River valley. The gravels overlie sandstone with the contact about 15 meters above the present-day river level.

2. Mapping

2.1 Preparatory and Reconnaissance Phase

On the basis of the preparatory and reconnaissance stages, the two areas of study were divided up into four discrete "settings" wherein similar environments of groundwater flow exist. Settings I and II occur in the east area (Fig. 6a), and settings III and IV in the west area (Fig. 6b).

In setting I, the maximum local relief is approximately 150 meters (490 feet) over a distance of five kilometers (3.1 miles). The slope is composed of three segments: the steep slope of the highland (1 in 25); the steep slope of the river valley bank, almost vertical in places; and the less steep intermediate slope (1 in 90).

Setting II has a maximum local relief of approximately 170 meters (550 feet) over a distance of eight kilometers (5 miles). The slopes of the river valley bank and the highland are steep, as in the previous case. The intermediate region is composed of extensive areas of low slope; a reverse slope is present in one instance, causing a broad shallow topographic low. The variability of the general slope is caused at least in part by the presence of aeolian material. This material presents numerous local highs and lows on the general slope, and also reduces the over-all slope of the intermediate region. The aeolian material extends from the top of the Red Deer River valley bank, to approximately one half the distance to the base of the steep slope from the highland. The small stream which is a tributary to Waskasoo Creek occupies a linear depression west of the local high area caused by the dunes.

Setting III has a maximum local relief of approximately 90 meters (290 feet) over seven kilometers (4.4 miles). A steep slope borders the highland, and the adjacent lowland has a less steep slope. Between the highland and the thalweg occupied by the Medicine River, a topographically low area is present, in part

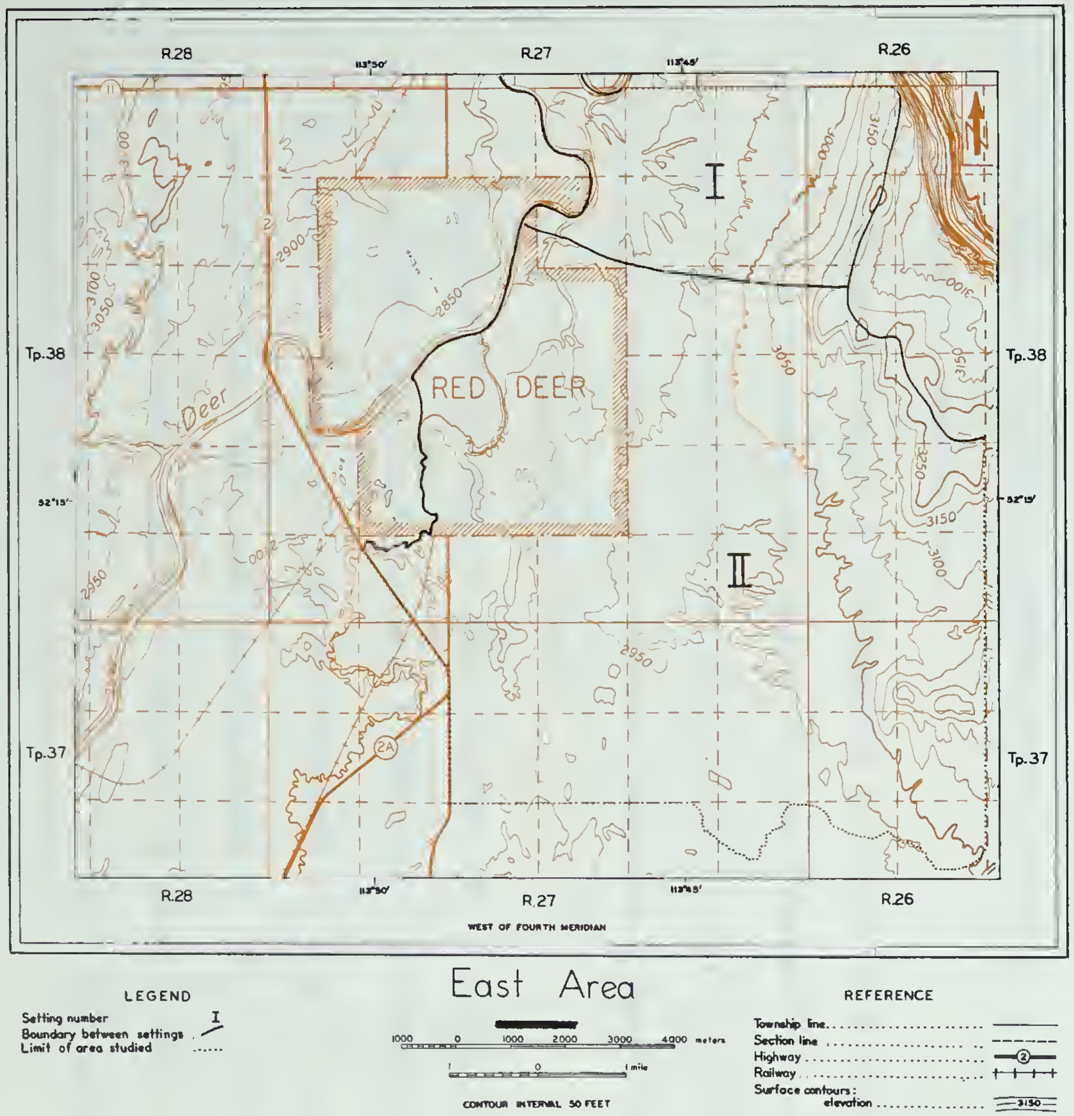

Figure 6a. East area: Map outlining areas wherein similar environments of groundwater flow exist (settings)

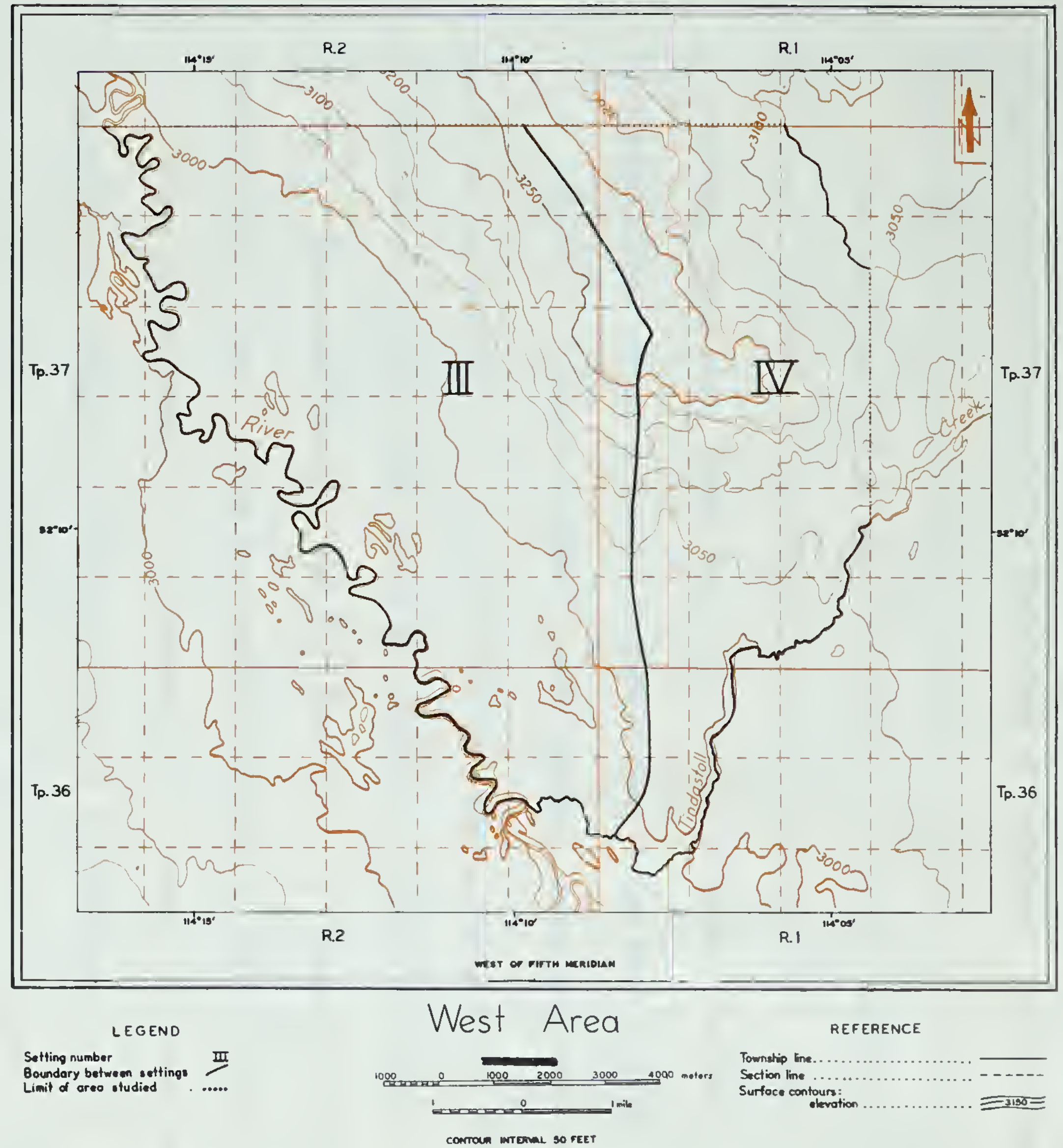

Figure 6b. West area: Map outlining areas wherein similar environments of groundwater flow exist (settings)

because of aeolian material on both sides of the river. Aeolian material also forms local topographic lows and highs on the lower part of the lowland slope.

The maximum local relief in setting IV is approximately 80 meters (260 feet) over a distance of approximately four kilometers (2.5 miles). The highland has a relatively steep slope bordering it, while the adjacent lowland is nearly flat with Tindastoll Creek almost stranded in places due to the lack of sufficient gradient.

On the basis of the initial investigation, major groundwater flow systems would be expected to start on the highlands, terminating in the adjacent lowlands. In the east area, some flow would be expected to reach the river, especially in setting I. The steep banks of the Red Deer River are expected to have local systems associated with them, as are the aeolian deposits in both the east and the west areas.

The reconnaissance of the areas did not reveal too many features which at the time could be related to a relative surplus or deficiency of water. Three springs, one area of soap holes, one area of "soap-hole like" features, and a sparse scattering of salt precipitates were the extent of features indicating a relative surplus of water. Definite features indicating a relative deficiency were not observed, but inferences could be made at some locations.

In the east area, at E-1 (Appendix A), there were indications of a relative surplus of water occurring over an area of approximately four square kilometers. For this reason, the detailed study was started at this location, so that an appreciation of the features associated with a relative surplus could be obtained.

2.2 Detailed Mapping Phase

The proposed traverses of the area were set up on a grid pattern. The grid spacing was 500 meters east-west and 3,500 meters north-south. The actual route of the traverse in almost all cases deviated from the line of the grid. Deviation from the grid lines in some cases and from the pattern in others, was determined from aerial photographs before starting a traverse, by observation in the field and, in many instances, by a combination of both. The basic grid pattern was established

to maximize the use of existing roads and yet provide as detailed a coverage as was deemed necessary.

Tóth's classification of observed phenomena is given in table 1. The features listed in this classification were used to determine locations to be visited in the initial part of the Red Deer study. During the study, some of the features listed by Tóth were investigated in more detail. This was done for two reasons: first, to become familiar with the different physiographic features; and second, to investigate the validity of the conclusions obtained by Tóth. In addition, other features were also investigated. A discussion of the individual features and their interpretation is given in the next two sections.

For each area, a complete list of all the observations and traverses along with their location, elevation, and the main point of consideration is given in Appendix A. A map showing the location of each point accompanies the list of each area. The observation-point numbers in the lists contain a preceding letter "E", denoting the east area, and "W", denoting the west area. The usage in the text is in agreement with these lists. However, on the map for each corresponding area, numbers for observation points and traverses are presented without the preceding "E" or "W" designation.

2.3 Summary of Results

In this section, the highlighting of certain features is intended. These features are dealt with in terms which will be a basis for their interpretation. Each feature will be dealt with as individually as is possible.

a) Springs

A spring is a location where water is discharged naturally from within the lithosphere, upon it, in amounts that are discernible.

In the two areas studied at Red Deer, sixteen springs were observed (Fig. 7a and 7b). Six of the sixteen springs were in the east area, and the remaining ten were in the west area. The rates of discharge vary from less than one liter* per minute at

* 1 liter = 61.02 in.^{3} = 0.22 gal. (Imp.)

Table 1. Tóth's classification of observed phenomena related to relative surplus and deficiency of water at the land surface relative to that which can be attributed to surface water (after Tóth, 1966b, p.32)

Features pertaining to water:

a. aspects of the actual presence and of the physical and chemical properties of water;

springs
seepages
groundwater levels
chemical quality of water (distribution of the chemical components)
physical quality of water (temperature, turbidity, etc.)

b. aspects associated with the presence or absence and with the physical and chemical properties of water;

natural vegetation
salt precipitates
"burnt crops"
"soap holes"
moist depressions
dry depressions
man-made objects and local reports*

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*This point is not considered in this study.

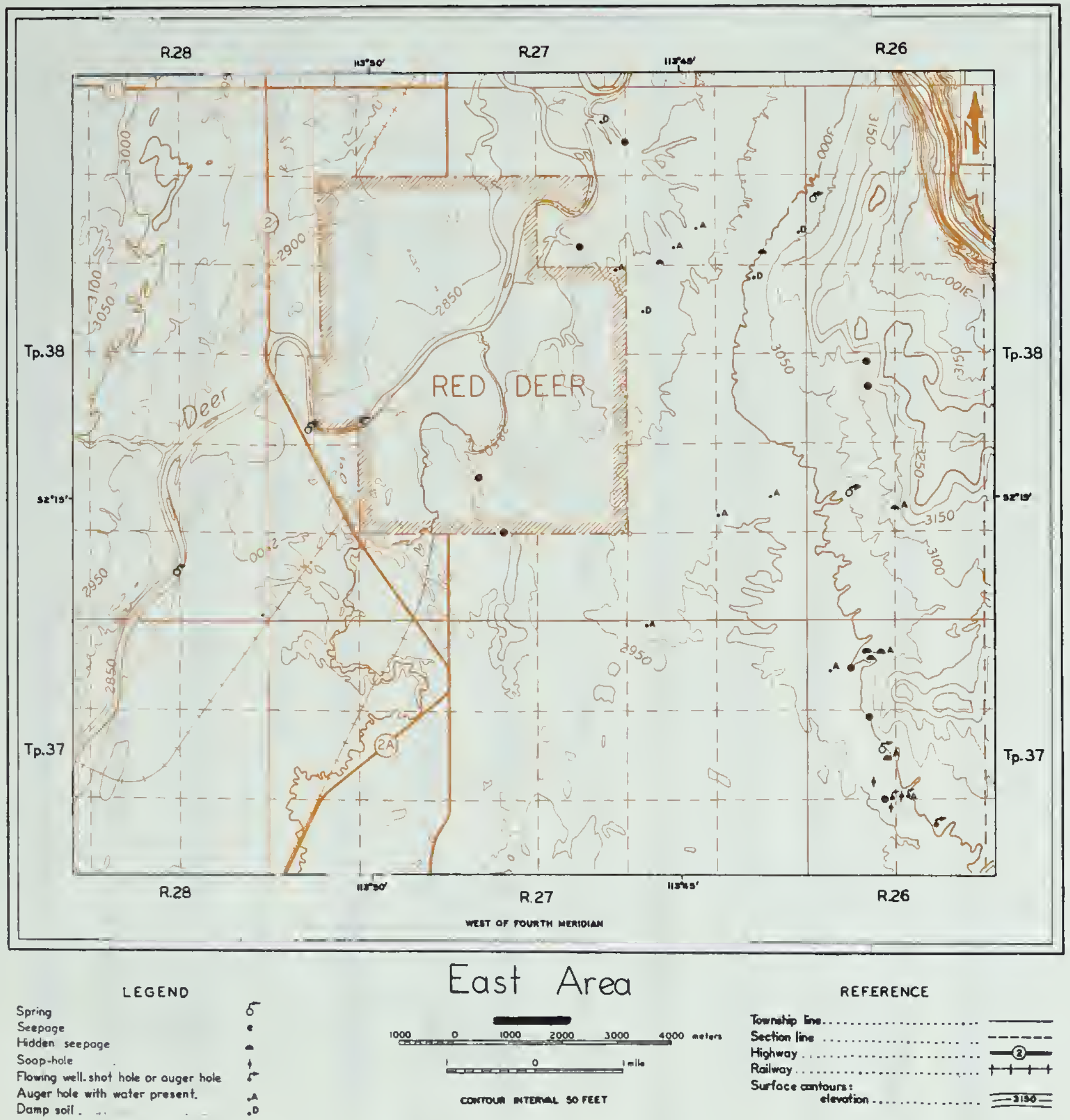

Figure 7a. East area: Location and distribution of springs, seepages, hidden seepages, damp patches, auger holes in which water was encountered, and soap holes

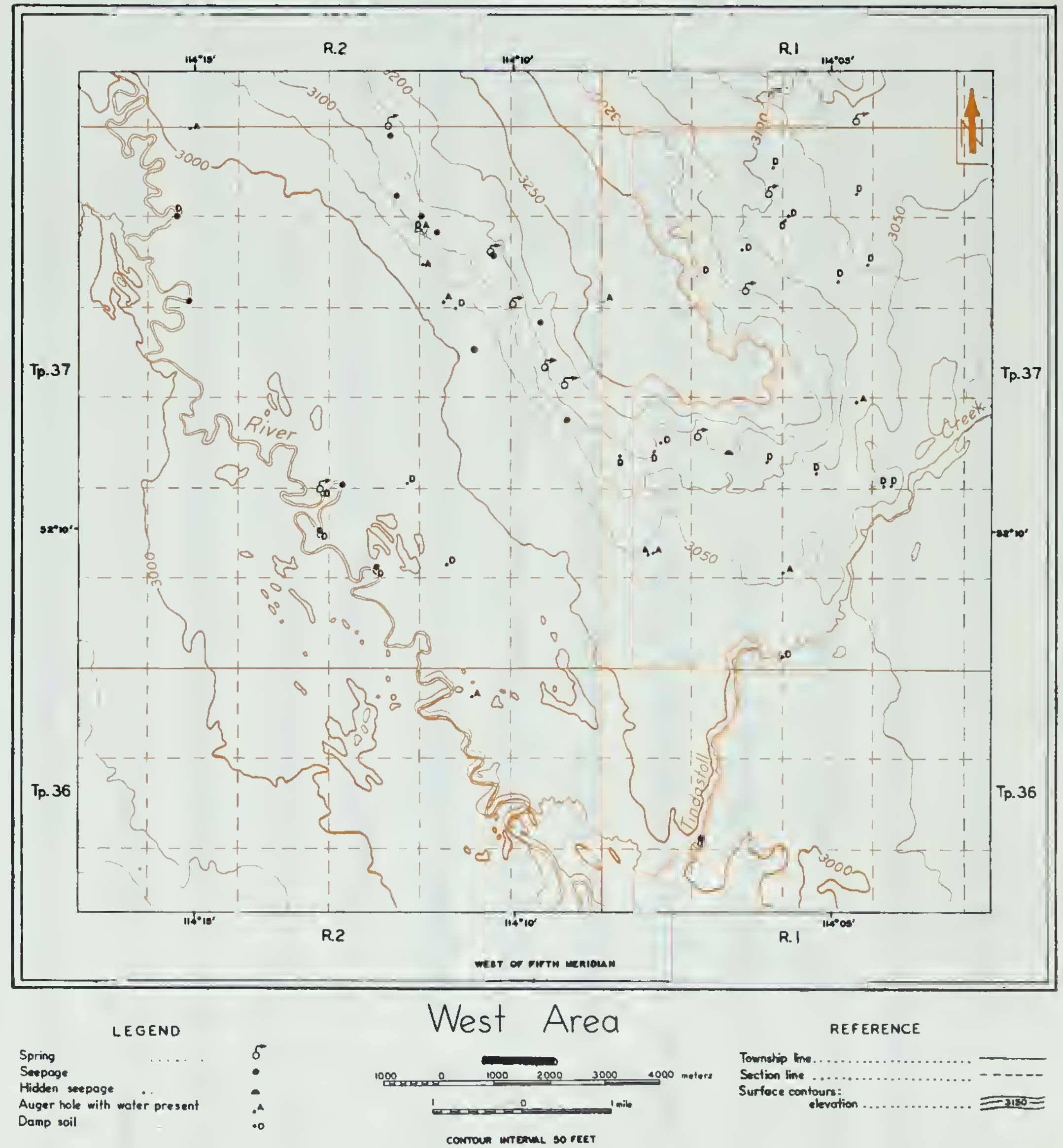

Figure 7b. West area: Location and distribution of springs, seepages, hidden seepages, damp patches, and auger holes in which water was encountered

W-113, to approximately 400 liters per minute at W-12.

In the east area, half of the springs are found toward the base of the steep slope of the highlands, and the others are present in the lower half of the bank of the Red Deer River valley. The west area has nine springs in the lower half of the steep slope of the highland, and only one on the bank of the Medicine River.

The material from which the springs are discharging was evident only at three locations. At observation points E-210 and E-211, the water discharges from the contact between gravels and the underlying sandstone. At observation point W-12, the water issues from fractures in a sandstone.

A spring is an obvious location wherein a relative surplus of water exists. A spring is a cornerstone in groundwater mapping, not only as an obvious point of groundwater discharge, but also for an interpretation of some associated features. These associated features permit a logical interpretation of relative water conditions at locations when springs are not present.

b) Seepages

A seepage is the naturally occurring diffuse discharge of groundwater in the liquid state from within the lithosphere, upon it, at an average rate which is not discernible, but is equal to or exceeding that of local evapotranspiration.

Nineteen seepages were observed in the two areas (Fig. 7a and 7b), nine in the east area, and ten in the west area. The seepages in both areas are distributed within the same parts of the basins as the springs, that is, the lower half of the highland slopes and along the river valley banks. The two seepages associated with the Red Deer River valley are found in short, deeply incised linear depressions within 1,000 meters of the valley proper. Two other seepages were observed on the banks of the tributary to Waskasoo Creek.

The expanse of obvious seepage points covers areas up to about 60 meters in diameter as is the case of E-118a. However, the expanse of a unique combination of a spring and seepage area at W-140 covers approximately 2.5×10^5 square meters.

Seepages were definitely identified by various means. In some cases, the diffuse discharge of the seepage became concentrated in a linear depression leading from the seepage area. This was the case at E-1 (d-3), W-1, W-49, and W-102b. At W-14, the presence of hydrophytic vegetation over a change in elevation of about one meter, with no possible means of surface water being dammed up, was sufficient to identify the presence of a seepage.

In some cases it is difficult to determine whether seepage is occurring at a particular location or whether the water is of surface origin. Where doubt exists, some additional features must be used to identify the seepage positively.

Seepages at E-117c and E-118a are found at the base of a crescent-shaped steeper slope on an otherwise uniform slope. Over the majority of the area of obvious seepage, an extremely hummocky ground prevailed, as at E-118a, W-1, and other locations. These hummocks are up to approximately ten centimeters high and are approximately ten centimeters in diameter. Their form is very similar to, but they are smaller than the earth hummocks discussed by Washburn (1956).

A definitely identified seepage in an important phenomenon in the mapping of groundwater, for the same two reasons as springs. At seepages, however, the value of associated features is greater than at springs. This results from a variation in the rate of discharge of groundwater over the extent of the seepage area, giving rise to a larger array of associated features at seepages than at springs.

c) Hidden seepages

A hidden seepage is a location at which the groundwater level is close to the land surface, with groundwater moving toward it. Hidden seepages commonly occur on slopes or in linear depressions, and are often indicated by the presence of hummocky ground. This condition prevails at several locations in the area of study (Fig. 7a and 7b). In some instances, water could be found on the surface between the individual hummocks but, in other cases, there was no water present.

At observation points E-1 (f-1), E-47a, E-97a, and E-141b, small-diameter holes were augered. In all cases, the ground was hummocky on a slope or in a linear depression at the base of a steeper portion of the bank, and in all cases, water was encountered within a depth of two meters. The relatively constant position of the water levels observed in the auger holes was indicated at observation points E-1 (f-1), E-47a, and E-97a. At these locations, the water levels were observed on at least two different occasions during the field season. A chemical analysis of the waters obtained from the auger holes indicated that the water was of the same type as waters analysed from springs and seepages in adjacent areas and also from springs and seepages in the same relative position in the drainage basin.

At present, hummocky ground on even slopes or banks of linear depressions has been interpreted as being a location where groundwater is close to the surface. This is based upon the stability of the water level in the auger holes, and the chemical similarity of the water from the auger holes to that at adjacent points of groundwater discharge. At some locations damp soil*, rushes*, or damp soil and rushes may be present on the surface at these locations. The location of the hummocky ground in areas of a surplus of water just below the land surface on slopes strongly suggests that the presence of the surplus water plays a role in the formation of the hummocks. The role, however, if it exists, is not known at present. If a relationship could be shown to exist, then the interpretation of similar features under other conditions could be made, for example, when hummocky ground is present in a closed depression.

d) Damp soil

Damp soil in this report refers to soil which remains damp, even though it is exposed directly to the elements of evaporation, while soil in adjacent areas under similar conditions is dried. Damp soil is found as a continuous patch, or as a series of discrete patches over an area of limited extent. Damp soil is commonly

*Discussion following.

found in closed depressions, on slopes, and on relatively flat ground.

Damp soil was found in numerous closed depressions over most parts of the two individual areas. Very commonly these depressions were detectable because of their lack of complete vegetation cover, resulting from cultivation in the drier years.

Damp soil patches are found on relatively uniform slopes lacking any perceptible closed depressions at several locations in both areas. Three such locations are E-127, W-39, and W-136. At these locations, the soil was more moist at the surface than in the surrounding area. Locations E-127 and W-39 were both observed at least two days after the last rain and both areas covered approximately 2×10^3 square meters. W-136 is approximately 1.5×10^2 square meters in areal extent. At this location, the ground (on a slope of approximately 1 in 50) was so damp that it "squished" like a wet sponge when walked upon. This latter observation was made at least ten days after the last rain.

Discrete patches of damp soil a few centimeters in length were observed at E-140d (Plate II, A). Across the road from this observation there were some patches a few meters in length. At W-132, several large discrete patches of damp soil were observed over an area of approximately 2.5×10^5 square meters after at least nine days without rain. Several of the larger patches at W-132 are visible in plate II, B The photograph of plate II, B was taken looking downslope; the majority of the patches visible are on the flanks rather than in the lows of small irregularities of the regional slope.

Salt precipitates* were found associated with some damp patches. In some instances, the damp soil was present in the soil profile and the salt precipitates delineated the upper limit of the damp soil. In other cases, the damp soil was on the land surface, with the salt precipitates present around the periphery of the

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* Discussion following.

Photograph showing small discrete patches of damp soil (dark color) bordered by salt precipitates at E-140d. Plastic ruler near center is 15 cm. long.

A

B

Photograph showing the distribution of large patches of damp soil in the field at W-132. The photograph was taken after at least nine days without rain.

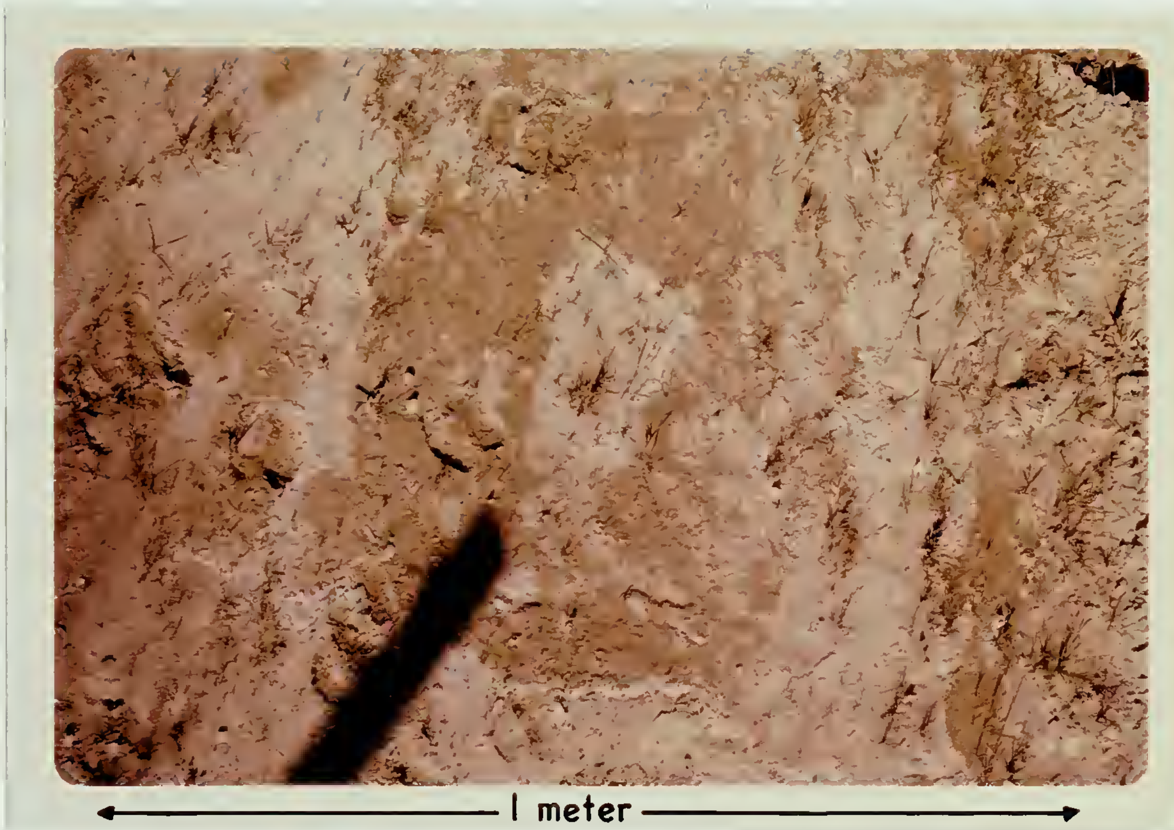
PLATE II

damp soil patches. At E-132c, damp soil capped by a small amount of salt precipitates was observed in a gopher hole; at E-138b and W-62, a similar phenomenon was observed in a road cut exposing the soil profile. At E-140d (Plate II,A), W-98, W-141, and W-156 (Plate III), damp spots were observed on the land surface with a border of salt precipitates. The distribution of damp soil patches is given in figure 7a and 7b.

The damp patches are believed to indicate a relative surplus of water below the land surface. Damp soil in patches is thought to be the result of differences in the permeability of either the surface or the underlying near-surface material. The depth to the saturated zone will be greater as the diameter of the openings, acting as capillary tubes, become smaller. However, as the diameter decreases, the rate at which water can rise in the capillary zone decreases. Because the rates of movement are small and because the diameter of the openings are small, the volumes of water rising in the capillary zone will be small. Small volumes of water at or near the land surface can easily be removed by evaporation and, therefore, no damp spots would be visible. For this reason, the depth to water cannot be excessive at locations where damp spots are observed.

Observation point W-11 is located on a slope, with damp soil on the land surface. An auger hole was dug at this location to a depth of 1.25 meters. The water rose in the auger hole to approximately 90 centimeters below the surface. The chemical analysis of the water from the hole was similar to the chemical analysis of the water from the spring at W-12 (less than one kilometer distance).

Damp soil is interpreted as indicating that water is close to the land surface. When the damp soil occurs on slopes, it is reasoned to be the result of groundwater. On flat land, or in closed depressions, additional observations are needed to conclude that the damp soil results from groundwater.



Photograph showing small patches of damp soil (dark color), outlined by salt precipitates at W 156.

PLATE III

e) Vegetation

Based on the identification of different plant species, Meyboom (1966) divided the lower part of the flank of Arm River valley, Saskatchewan, into four zones. The sequence of plant communities in the Arm River drainage basin is the result of two factors: first, the direction of groundwater movement, with respect to the land surface; second, the variation in the chemical quality of the groundwater moving toward the land surface at different distances from the thalweg.

The identification of different plant types requires the assistance in the field of a botanist, or some previous knowledge of plant taxonomy. Neither of these prerequisites was met in the study at hand; therefore, identification of plant communities and their distribution in the water basin could not be used to the greatest possible degree in studying groundwater motion. However, the study of the distribution of four selected species of plants, along with observations of the variation in growth and species of plants over a restricted area, was very useful.

The general growth of certain plants over a limited area indicates whether growing conditions are favorable, adverse, or average, relative to the adjacent areas. Plate IV, A shows a variation in cultivated vegetation.

The failure or retarded growth of the cereal crop may be indicative of less-fertile soils*. Plate IV, B shows a variation in natural vegetation. The spruce trees in the background prefer moist conditions for growth; however, they are not growing in the foreground because there is too much water present. The absence of trees in an otherwise uniform coverage is easily detected on aerial photographs. This observation is especially useful when planning traverses; for example, it led to the discovery of the seepage at E-117c.

A lush growth of hydrophytic[†] vegetation indicates that moist conditions exist at a location over at least part of the year. This observation is mose useful

*Discussion following.

† Hydrophytes are plants living completely or in part submerged in water, or with their roots in the zone of saturation.

A

Photograph showing how areas of different soils can be located because of nonuniformity in the growth of cultivated vegetation at W-114.

B

Photograph showing a nonuniform growth of natural vegetation at W-140. Spruce trees in the background suggest moist conditions, but their absence in the foreground suggests too much water.

PLATE IV

when a lush growth of hydrophytic vegetation is present over a change in elevation with no means of surface water being dammed up. In this instance, the moist conditions must result from the discharge of groundwater. At E-1 (g-4), E-104a, and W-14, a lush growth of hydrophytic vegetation over a change in elevation led to the detection of two springs and a seepage.

The four plant species used in this study were Baltic rush, Juncus balticus; spruce trees, Picea glauca or Picea mariana; wild barley or foxtail, Hordeum jubatum; and red samphire, Salicornia rubrum. With the exception of the spruce trees, all of the above species are highly salt tolerant (Meyboom, 1966, after Budd, 1957; Dodd, 1960). The species Juncus balticus and Salicornia rubrum are also phreatophytes[tt].

The Baltic rush was observed at many locations where subsurface waters were encountered in auger holes less than two meters in depth. This confirmed the fact that the species is a phreatophyte; its presence suggests that saturated soil is within two meters of the land surface. The fact that the Baltic rush was found standing in water on very few occasions further suggests its dependence on subsurface water rather than surface water. The distribution of Baltic rush occurrences in the two areas is given in figures 8a and 8b.

Spruce trees may also be indicative of more moist conditions. The presence of spruce trees over a limited area definitely warrants a closer investigation. Spruce trees were found associated with springs and seepages at several locations, for example, E-202, W-120, W-124, and W-140.

Wild barley is a specific indicator of generally adverse growing conditions. This plant can be found inhabitating areas of less-fertile soil* where few other

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ttPhreatophytes: "A phreatophyte is a plant that habitually obtains its water supply from the zone of saturation either directly or through the capillary rise." (Meinzer, 1923, p. 55).

*Discussion following.

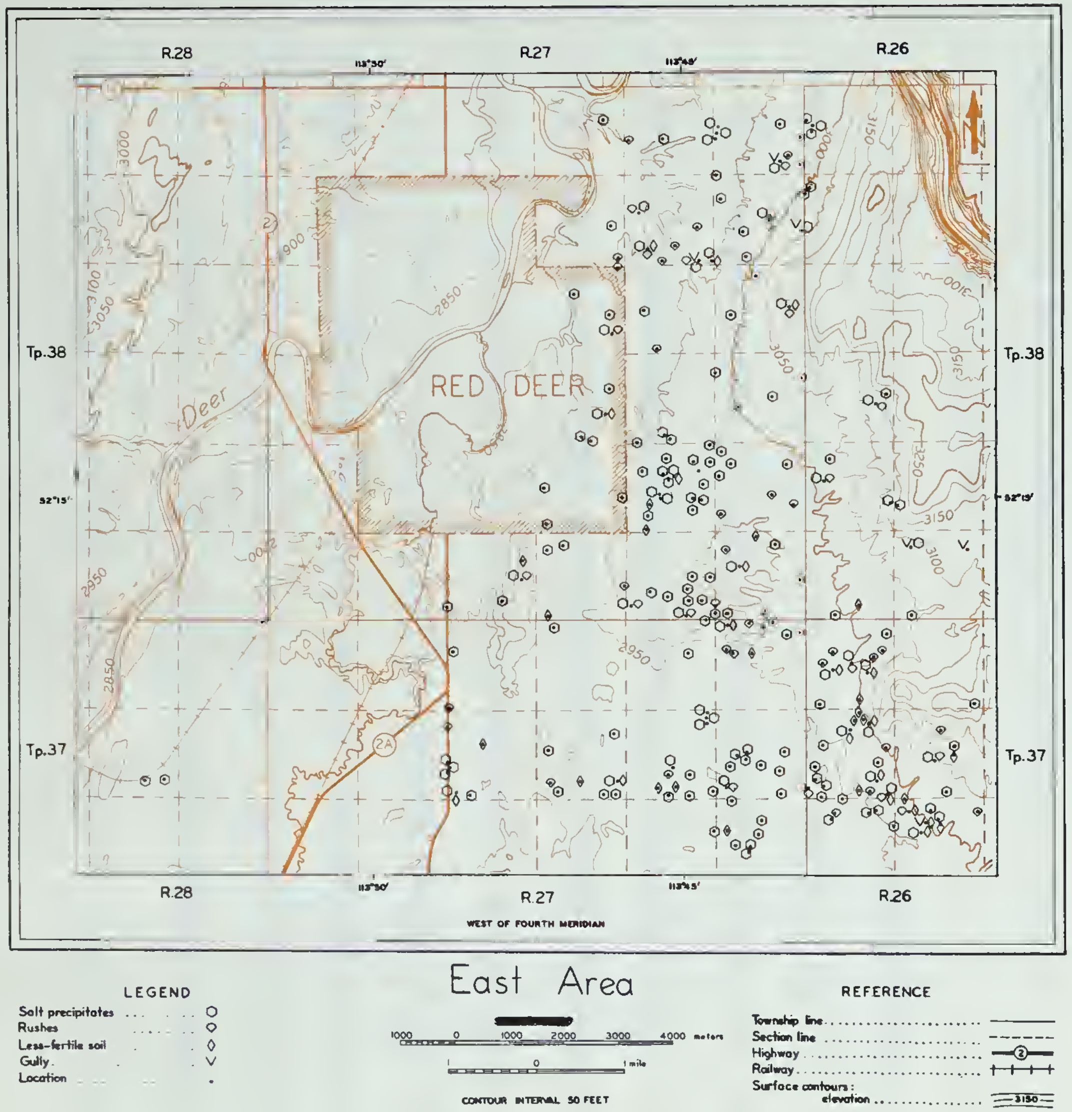


Figure 8a. East area: Location and distribution of salt precipitates, rushes (Juncus balticus), less-fertile soils, and gullies

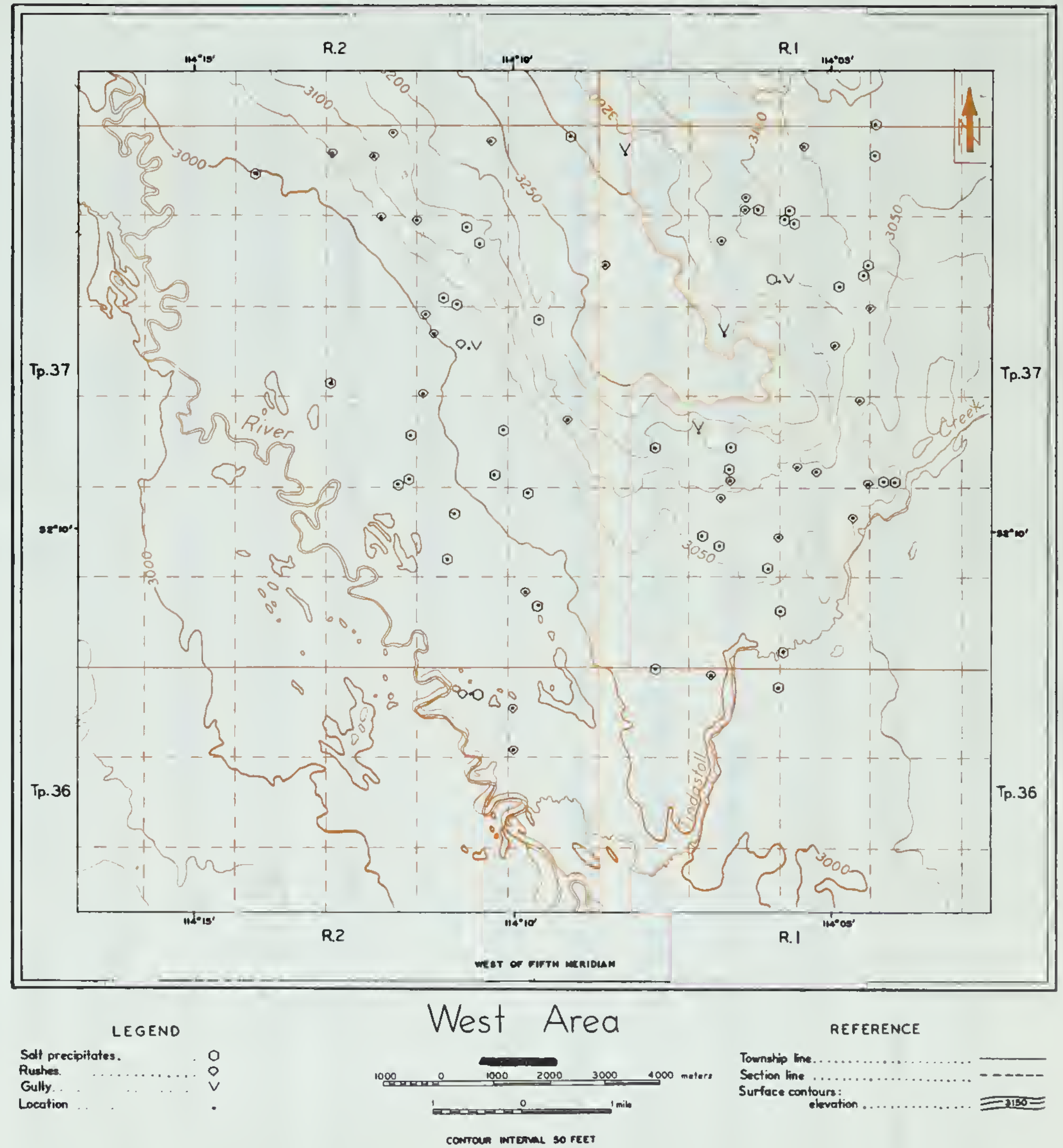


Figure 8b. West area: Location and distribution of salt precipitates, rushes (Juncus balticus), and gullies

plants will be found. The plant is a useful indicator in areas of natural vegetation in which variation in vegetation is not manifested in the same manner as in areas of cultivated vegetation. Instead of absent or stunted growth of the vegetation, there is generally a variation in the species of plant present. Despite its report as a phreatophyte, red samphire is found under what on the whole appear to be generally adverse growing conditions (Plate VIII). In the Red Deer area, this plant is found at a few points in the area E-1, and at location W-81a. At each location, the plant was found growing in less-fertile soils*.

Vegetation was used mainly to direct attention to certain conditions. The presence of Baltic rush and hydrophytes over a vertical change in the land surface were the only instances in which the resulting vegetation could be attributed to groundwater. The presence of spruce trees, or the absence of trees, only suggests a possible relative surplus of water. The absence or stunted growth of cultivated vegetation in an otherwise uniform growth, and the presence of wild barley and red samphire only serve to indicate less-fertile soil areas*.

f) Salt precipitates

The salts dissolved by waters moving under the land surface must be deposited upon evaporation of the water. The intensity of the salt precipitates is proportional to the amount of total dissolved solids in the water. Therefore, intense patches of salt precipitates are expected with waters having a high total dissolved solid content, and patches of almost indeterminable amounts of salt precipitates are expected from water having a low total dissolved solid content.

Tóth (1966b) had eight salt precipitate samples from the Trochu area analysed chemically. The main salt components of the samples were Na_2SO_4, $CaSO_4 \cdot 2H_2O$, $MgSO_4$ and $NaHCO_3$. Characteristics used in the field to determine the different types of salts are as follows: Na_2SO_4 salts have a definite salty taste; $NaHCO_3$ is soluble

*Discussion following.

in 20% HCl; if a salt precipitate does not taste salty or effervesce in HCl, then it is assumed to be either $CaSO_4 \cdot 2H_2O$ or $MgSO_4$.

In the field, salt precipitates are easily recognized, either by their whitish, light grey color in dry weather, or by the adverse effect they have on plant growth. When salt precipitates are intense, they can be observed on aerial photographs by a light tone. In the present study, only a few instances were found where the salt precipitates were intense enough to be observed on the aerial photographs.

Generally, the deposits of salt precipitates in the Red Deer area were not intense, a canclusion also reached during the reconnaissance survey. Salt precipitates, where identified using the previously mentioned field criteria, were found to be $CaSO_4 \cdot 2H_2O$, $MgSO_4$ or Na_2SO_4.

As was noted earlier, if water is low in dissolved solids, it will leave only a trace of salts upon evaporation. In some cases, the only evidence of salt precipitates is thought to be a light grey tinge to the soil. At several locations, a gradation from a soil with a light grey tinge into an obvious location of calcium or magnesium sulphate salts was observed. The light grey coating is thought to be the result of evaporation of water with a low total dissolved solids content.

The distribution of salt precipitates in the east area is mainly below the 3,150-foot contour line (Fig. 8a). There are three small separate areas in which there is a higher density in the occurrence of salt precipitates. The three areas are as follows: 1) the extreme southeast corner of the area of study, within a kilometer or two of the small intermittent creek; 2) the relatively flat area located in part in Sec. 12, Tp.38 , R.27 , W. 4th Mer. coinciding with the enlargement of the lowland area by the eastward shift of the highland; 3) the very broad, shallow linear depression located in part in Sec. 1, Tp. 38 , R. 27 , W. 4th Mer.

In the west area, the salt precipitates are also mainly restricted to locations below the 3,150-foot contour line (Fig. 8b). However, even below the 3,150-

foot contour line, there are very few occurrences of salt precipitates. Where salt precipitates are present, the deposits are generally not large in areal extent, nor are they intense.

Dissolved mineral matter may be present in either groundwaters or surface waters, but the amounts are generally larger in groundwater. The presence of salt precipitates, therefore, does not indicate necessarily that groundwater is being evaporated. However, a relationship between salt precipitates and groundwater discharge does exist. In recharge areas, the salts dissolved by waters are moved downward, away from the land surface. In discharge areas, the surfaceward-moving groundwaters contribute salts to the land surface. Also any salts dissolved by surface waters are kept at the land surface because the surfaceward-moving groundwater does not allow the surface waters to infiltrate and carry the salts downward from the land surface.

The presence of salt precipitates, therefore, is indicative of surfaceward-moving groundwater which either evaporates on the land surface or prevents surface waters from infiltrating and carrying dissolved salts downward from the land surface.

g) "Quick-ground"

The term "quick ground" is used in this report to refer to locations where a part of the land surface is characterized by a local weakness resulting from an excessive pore-water pressure.

This condition is manifested in two different features, namely "soap holes" and "swamps". A separate discussion of each feature follows.

-soap holes - Soap holes have been described by Tóth (1966b, p. 61) as "a part of the land surface characterized by a local weakness of limited extent underlain by a viscous admixture of sand, silt, clay, and water". In the Red Deer area, there were three main types of soap holes observed: a) "mound-type" (Tóth, 1966b); b) "flat-type" (Tóth, 1966b) and c) core-type.

Mound-type soap holes are accumulations of mud resulting from soap hole discharge. The area of discharging mud generally is unable to support the weight of a pebble a centimeter or so in diameter. Closer to the periphery, where the mud has dried forming a crust over the soft material, the ground will support the weight of larger animals.

The buildup of mud as seen in the Red Deer area was only a few centimeters at E-1 (e-8) (Plate V), but was close to a meter at E-1 (c-10b) (Plate VI). The morphologic expression in most cases appeared to be either an abrupt feature upon the land surface in the form of an irregular dome (Plate V), or a large broad cone shape opening downward (Plate VI).

A flat-type soap hole has a surface level with the surrounding land. This type of soap hole may have a thick or a thin dry crust covering the admixture of sand, silt, clay, and water. A thick-crusted soap hole (Plate VII, A) has a crust thick enough to support the weight of a man (generally at least 5 centimeters thick). A thin-crusted soap hole (Plate VII, B) is one with a crust not thick enough to support a man's weight.

Core-type soap holes (Plate VIII) resemble thick-crusted, flat-type soap holes with a mound of damp, medium-brown silt to very fine sand present in the central region.

The areal extent of the cores observed varied from a few square centimeters to a few square meters, though they were never more than 15 centimeters in height above the surrounding land. The cores of these soap holes were always damp. In some cases, salt precipitates were observed around the perimeter of the damp soil, as was the case at E-1 (e-3) (Plate VIII).

Soap holes observed were either discharging or non-discharging types; the nature of discharge varied considerably. In the case of E-1 (e-8, c-10b, and d-5), all mound types, the discharge is a viscous admixture of sand, silt, clay and water.

A small mound-type soap hole at E-1 (e-8) with an irregular dome shape.

PLATE V

A stereo pair showing a large mound-type soap hole at E-1 (c-10b) with a broad cone shape. Material being discharged is a viscous liquid, an admixture of sand, silt, clay and water.

PLATE VI

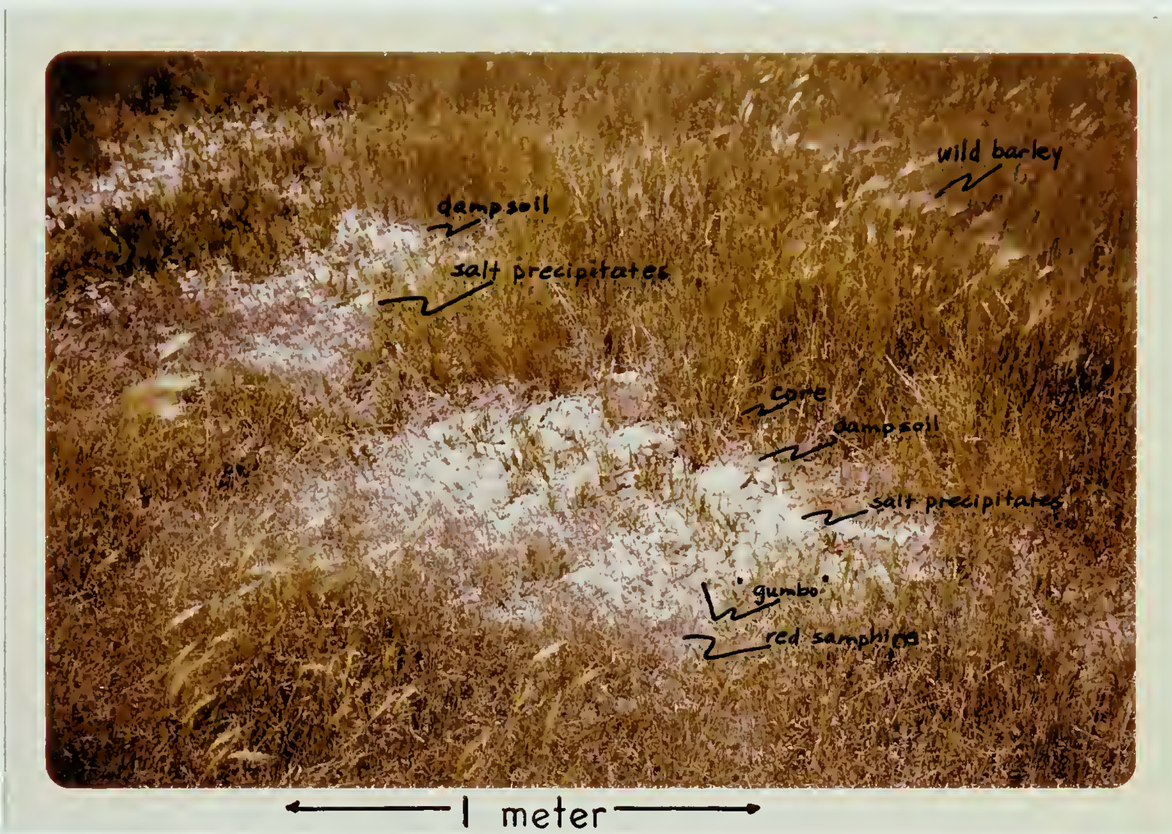
A

Photograph showing a thick-crusted, flat-type soap hole at E-1 (c-8). The medium grey material present in the center oozed out of an auger hole.

B

Photograph showing a large, thin-crusted, flat-type soap hole at E-1 (e-6).

PLATE VII



Photograph showing a core-type soap hole and associated phenomena at E-1 (e-3).

PLATE VIII

Dr. S. Thomson (written communication, 1966) from the Department of Civil Engineering, University of Alberta, determined the water content and particle size distribution for samples from d-5 and c-10b. The average water content (weight of water/ weight of solids) was found to be 67.7%. The particle size distribution given in figure 9 shows that 21% of the total weight of the sample was composed of particles greater than 1/16 millimeter in diameter, 41% was between 1/16 millimeter and 1/256 millimeter, and 38% was less than 1/256 millimeter.

The mound-type soap hole at E-1 (c-10a) discharges water at a rate of a few milliliters per minute. The discharge point is the apex of the thick-crusted, mound-type soap hole, 6 meters east of c-10b.

Some flat-type soap holes had water standing on their surface over an interval of time measured in weeks. For example, at E-1 (c-8) water was present on the surface every time the observation point was visited; one visit was after 22 days without rain. However, water was never seen to be flowing away from any of the flat-type soap holes with water standing on their surfaces. At other soap holes, the surface material was damp every time observations of the soap holes were made. Such was the case at many core-type soap holes, as well as some flat- and mound-type occurrences. In some instances, the only indication of discharge was the presence of salt precipitates on the surface of the feature.

The non-discharging soap holes have no evidence of either mud or water discharging onto the soap hole surface. Generally, in these cases, the admixture of sand, silt, clay and water occurs under a crust in the order of 5 to 10 centimeters in thickness.

A detailed investigation of four different occurrences of soap holes in the E-1 area was carried out using several small-diameter auger holes. The investigations indicated that a similar arrangement of three types of material can be found associated with the soap holes. Figure 10 (in pocket) shows a diagrammatic cross-section of one investigation from E-1 (c-10b) east through c-10a and c-10, to c-10c.

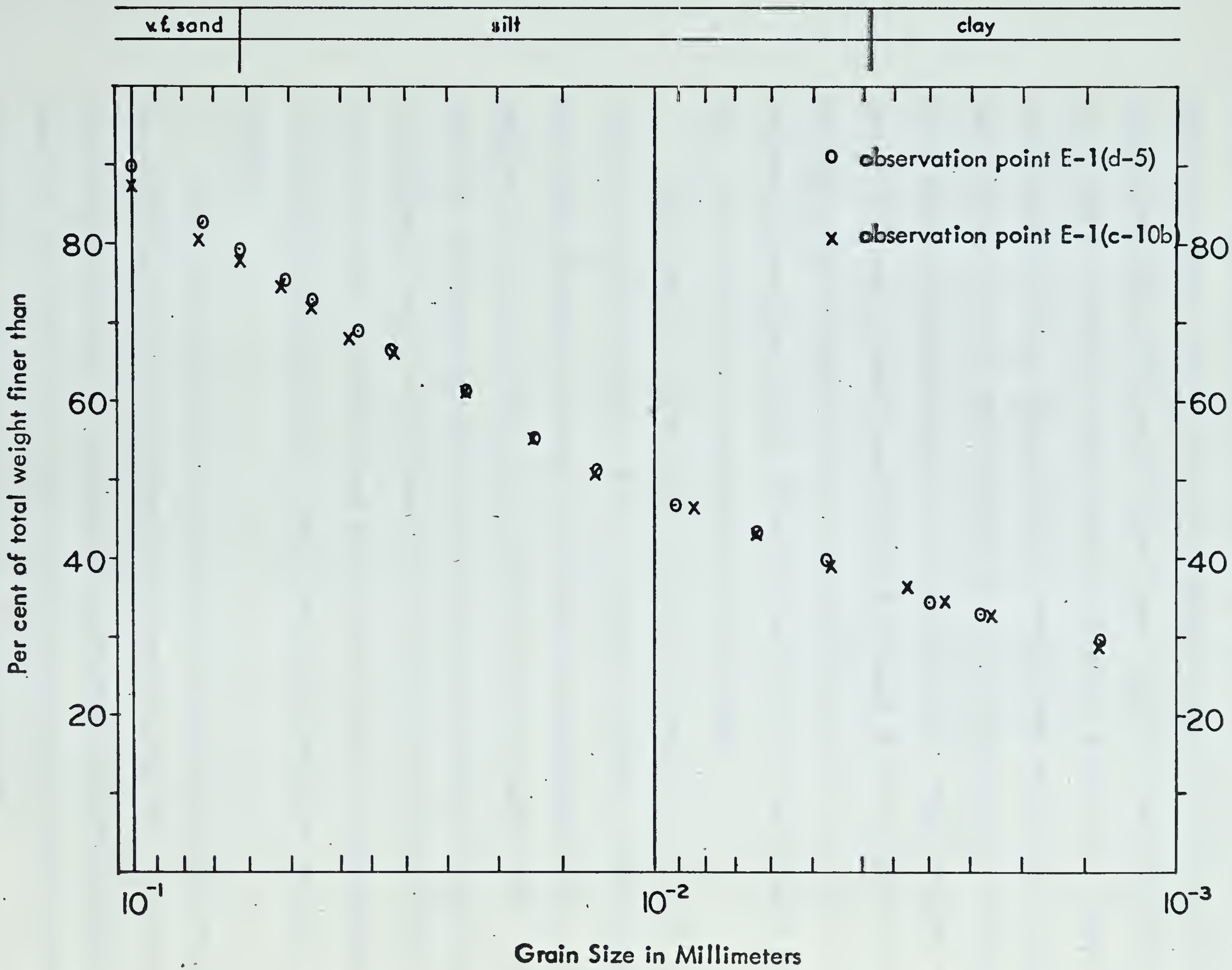


Figure 9. Relationship between the percentage of total weight and the corresponding grain size in millimeters of two samples of viscous fluid discharged at soap holes E-1(c-10b and d-5)

The characteristic material of the soap holes is the viscous liquid (type A material) being discharged at c-10b (Plate VI). This material was observed to be continuous between c-10b and a location immediately east of c-10 (Fig. 10). At the locations c-10b, c-10a and c-10, the viscous liquid is covered with little or no crust, while the intervening regions have a thicker crust present. Dr. Thomson (personal communication) has suggested that this material represents a condition wherein neutral stresses caused by upward-flowing water are in excess of the total stress caused by the weight of the particles making up the solid material. When the stress on individual particles due to upward-moving water is in excess of the weight of the individual particles, there is no longer any stress transmitted from particle to particle, and the admixture behaves like a liquid. When it is considered that groundwater is issuing from c-10a and c-10c, this interpretation is very plausible.

Associated with the soap holes is a wet, sticky material which is pliable like modelling clay (type B material, Fig. 10). The type B material, while possessing more solidity than type A material, is still unable to resist deformation by small pressures. The lack of strength of this material may be the result of either of the following: upward-moving water at rates less than those required to cause the material to become a liquid, as in the case of type A material; or the sliding effect resulting from failure of bonds between individual particles, due to the combination of a high (70%) montmorillonite content in the clay-size particles, and a high water content.

The third type of material associated with the soap holes is a dry, extremely hard, infertile, light-colored material (type C material, Fig. 10). This material, visible in plates VI and VIII, is the dehydrated counterpart of type A and type B materials. Type B and type C materials were also encountered at locations other than soap holes, and will be discussed under "less-fertile soils".

Of the 230 square kilometers mapped in the Red Deer area, soap holes

were found only in the area E-1. Their presence, therefore, suggests a unique combination of hydraulic and geologic conditions. The hydraulic condition is one of surfaceward-moving groundwater, and the geologic conditions are believed to be the presence of fine-grained unconsolidated sediments overlying a more permeable lens in the bedrock concentrating the discharge in the local area.

-swamps - In this report a "swamp" is that part of the land surface characterized by local weakness of limited extent, covered by a vegetation mat. The material underlying the mat, at observation point E-61, is a blackish-colored, slightly viscous mud. At this location, the small hand auger was easily pushed through the material to a depth of 155 centimeters.

At observation point E-61a, the land surface was very hummocky and flexible. The ground, when walked across, depresses and rebounds in much the same way as the mat on a trampoline, when it is walked across, depresses and rebounds. At this location a seepage was detected in the region of most flexible ground. A similar phenomenon was discovered at W-140. This location had springs and seepages associated with it over an area of approximately 2.5×10^5 square meters.

In the west area between the sand dunes by the Medicine River, slough bottoms were described by farmers as being flexible in various years. A farmer described the slough bottom at W-97 as a "floating" bottom. A second farmer related the story of how it had been necessary to use two pieces of window screen to cross the extremely flexible bottom of a slough in order that he could retrieve his fallen goose.

Though no definite evidence of seepages could be obtained from these sloughs, the association of salt precipitates*, light grey soil, and the presence of a flowing shot hole at W-87 tends to indicate that these flexible-bottom sloughs have some relation to the swamps.

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*Discussion following.

Detailed investigations of the swamps were not carried out. The main difference between swamps and soap holes appears to be the material with which the water is associated in the region of discharge. In the case of soap holes, the discharge is a sterile mixture (Plate VI), while swamps have a discharge of water only.

In short, the local weakness in the land surface at swamps is considered to be the result of neutralizing stresses caused by the upward movement of groundwater. The presence of both springs and definite seepages with two occurrences of the phenomenon supports this interpretation.

h) "Less-fertile soil"

It is generally realized that groundwater conditions play an important role in soil development. Unfortunately because of the lack of any previous training in soil science, the author was unable to use the distribution of soil types to aid in the determination of groundwater conditions except in very special cases.

In this report "less-fertile soil" is defined as regolith in which the growth of natural or cultivated vegetation cover is impeded relative to that found on the adjacent friable soil. The areal extent of any one patch of less-fertile soil or adjacent group of patches may range from a few square meters to a few square kilometers.

Three soils of differing appearance satisfy the above conditions. The first type of soil is locally referred to as "gumbo". This soil, where wet, is similar to type B material associated with soap holes, and where dry, is similar to type C material (Plate IX, A &B). The "gumbo" from E-112c has an extremely high pH (9.4), a high free lime and sodium content, and an electric conductivity of 0.9 millimho/cm.* Two water samples were taken from auger holes less than two meters deep in gumbo patches W-60 and W-67. The analyses (Appendix B) show that the waters have high total dissolved solids, sodium plus potassium greater than 80% of the total cations, and sulphates between 50% and 80% of total anions.

*Analysed by Agricultural Soil and Feed Testing Laboratory, University of Alberta.

A

Photograph showing the very smooth, hard, flat surface of an unfarmed "gumbo patch" at W-60.

Photograph showing the hard, uneven lumpy surface of a farmed "gumbo patch" at E-112c.

B

PLATE IX

"Gumbo" patches are found mainly at elevations below the base of the steep highland slopes (Figs. 8a and 11). They are found on hillsides at E-155d and W-64; in local low areas at W-147 and traverse W-149; and associated with flat-lying land in the regionally low areas at E-159e, W-71, and W-148.

The second type of less-fertile soil is characterized by surface soils in which the structure is that of hard, dense lumps a few centimeters in cross section. A hole augered in a patch of this type of soil at W-67a passed through type B material from 4 to 46 centimeters below the surface. A water sample was obtained from the auger hole at a depth of 140 centimeters. Analysis of the water (Appendix B) shows the water to have a high total dissolved solids content, sodium plus potassium equal to 90%, and sulphate content equal to 72%. The presence of type B material, the similarity of water quality, and the geographic proximity of this point to the gumbo soils at W-60 suggests that these two soils are different expressions of the same phenomenon.

The presence of water levels close to the surface at E-58, E-125b, W-54, W-60, W-67, W-67a, and W-68, and the relative stability of the water level, measured from September 13, 1966 to October 6, 1966 at W-67a and implied by the presence of the hand-dug wells at E-125b, W-54, and W-68, suggests that these forms of occurrence of less-fertile soils are related to water levels close to the land surface. The high total dissolved solid content of the water at W-60, W-67, and W-67a suggests that the water has been in contact with the ground for a relatively long interval of time. The presence of salt precipitates on the land surface at several locations indicates that water is not moving away from the land surface. An additional fact worth considering is that, according to local reports, it is possible to temporarily increase the fertility of these less-fertile soils by the addition of excessive amount of barnyard manure. However, the fertility decreases with time and after one or two years of increased fertility, the soil again becomes as unproductive as before the addition of the manure (Mitchell, Moss and Clayton, 1944). This suggests that the physical and chemical properties of

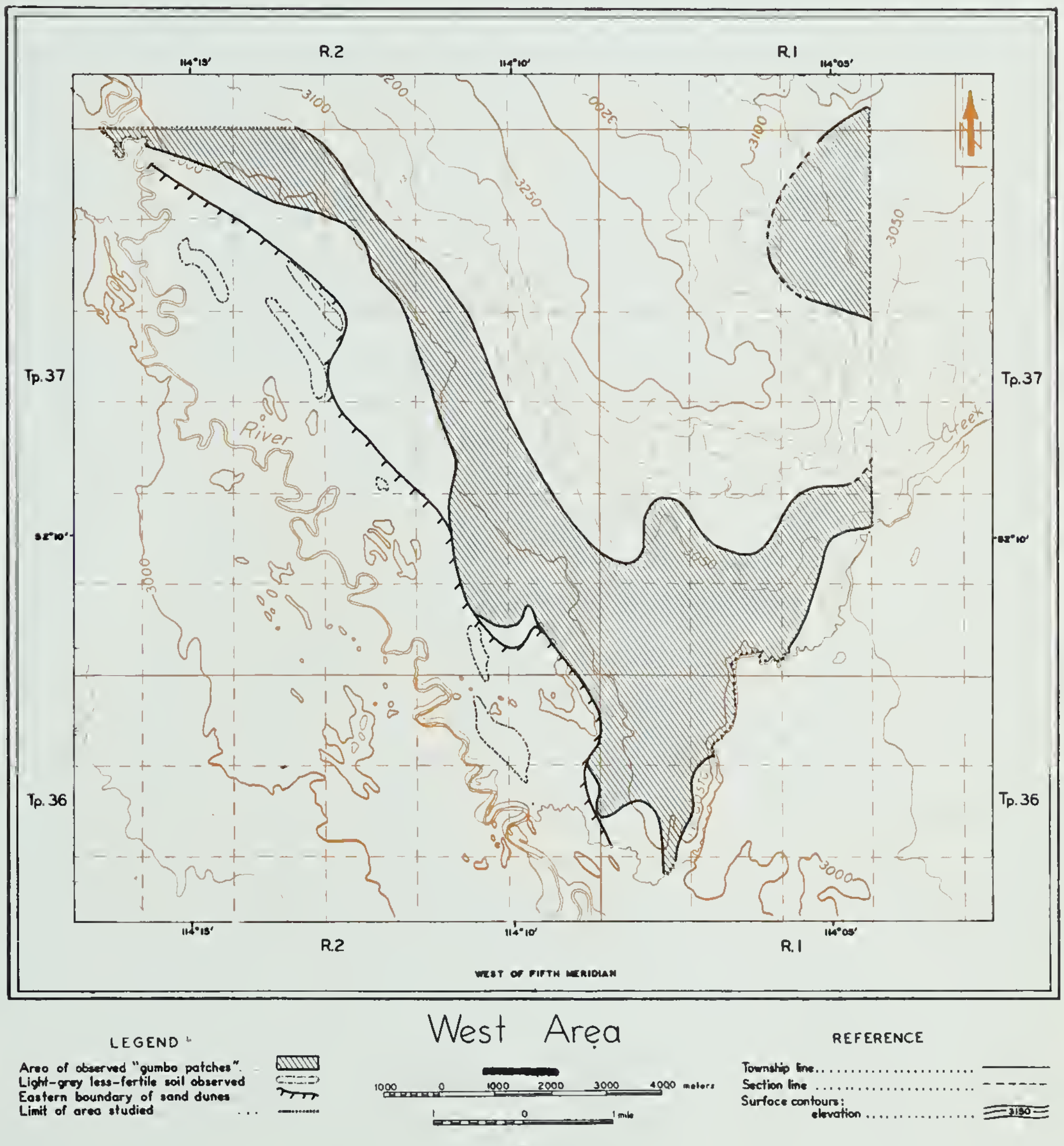

Figure 11. West area: Map showing the distribution of two types of less-fertile soil

these less-fertile soils are in equilibrium with a dynamic process. Because of the associated phenomena mentioned above, the dynamic process is interpreted as the continual addition of salts to the soil by discharging groundwater.

The third type of less-fertile soil is restricted to the local topographic lows in the dune area by the Medicine River (Fig. 11). Neither trees nor cultivated vegetation will grow in these lows; however, a lush growth of hydrophytic vegetation can be found in uncultivated lows. Where cultivated, the dry soils have a definite light-grey appearance. At W-82, the light-grey color was observed associated with an 8 millimeter thick crust. A water sample analysed from an auger hole less than two meters deep in the cultivated low at W-80 indicated that, on the basis of water chemistry, these less-fertile soils are different from previously mentioned less-fertile soils. The variation in fertility of the low areas indicated by the variation in vegetation strongly suggests a set of conditions similar to those existing at W-140 (Plate IV, B). At W-140 the variation in vegetation is governed by the amount of water present, which in turn is regulated by the rate of discharge of groundwater by the springs and seepages, and by the slope of the land. However, at a given point within the area of W-140, the amount of water present will remain essentially constant with time. If the same conditions prevail in the lows between the dunes, then the amount of water present must be relatively constant. A relatively constant water level indicates that the water in these depressions is in part groundwater.

The conclusion presented in the preceding paragraph is the same as those obtained under that portion of the discussion of swamps pertaining to the dune area. The conclusions from both parts strongly suggest that the water present on the surface in the topographic lows between the dunes is, at least in part, of groundwater origin.

i) Closed depressions

Closed depressions are probably the most commonly occurring physiographic features in any area. Unfortunately, the closed depression is perhaps one of the

most difficult to interpret. The difficulty in interpreting these features results from either the masking effect caused by the accumulation of water on the surface, or by the depressions being a point of discharge during part of the year and a point of recharge during the remainder of the year.

If a closed depression contains water, this water may be of surface, surface and groundwater, or groundwater origin. If the water is of surface origin, there are two possible reasons for the water not infiltrating. The first is that the bottom of the depression is impermeable; the second is that the ground beneath the depression is already saturated with water moving toward the land surface. The latter case will result in the accumulation of surface water if there is insufficient movement to bring the groundwater to the land surface in the depression, or in the accumulation of both surface and ground water if the groundwater does reach the land surface. The accumulating on the surface of groundwater alone would be observed only in the case of groundwater discharging at a rate which is sufficient to overfill the depression. However, in this latter case the prevailing groundwater condition is obvious.

The interpretation of the prevailing groundwater condition at a closed depression can be obtained if there are, associated with the depression, some additional phenomena related to a relative surplus of water. The associated phenomena may be salt precipitates, or some features indicating a relatively stable water level. For example, a relative surplus of water was deduced for E-153d for the following reasons: the presence of salt precipitates at E-153c and E-151a; and the relatively stable water level in the depression at E-153d during the entire summer, despite the broad, shallow nature of the depression and the lush growth of hydrophytes over the entire depression. The use of associated phenomena to deduce a surplus of water in the closed depressions in the local lows in the dune area adjacent to the Medicine River was outlined under less-fertile soils.

The interpretation of the chemical quality of surface water can be very complex.

Some factors governing the amount of dissolved material in surface waters are as follows: quality and quantity of groundwater discharged directly into the surface water; amount of soluble salts in the soil; amount of local relief of the catchment area; size of catchment area; amounts and rates of evaporation; and amounts and rates of precipitation.

In the Red Deer area the total dissolved solids* for several surface waters were obtained on September 24, 1966, twenty-four days after the last rain (Fig. 12). A general increase in total dissolved solids away from the highlands is believed to be qualitatively indicative of increasing total dissolved solids in the groundwaters. The interpretation is believed to be valid for two reasons: first, after twenty-four days without rain, there is a possibility that the depressions containing water may do so only because groundwater is being discharged into them; second, if the water is mainly of surface origin but in a discharge area, it will contain salts which, at least in part, have been derived from the precipitates of evaporating groundwater. With such a simple interpretation of so many variables, there will inevitably be exceptions. However, the general results in this particular case appear to be reasonable.

Meyboom (1966) investigated a depression in hummocky moraine in a regionally high area, Allen Hills, Saskatchewan. He found, using piezometers, that the local lows in the hummocky area serve as discharge areas for part of the year, and as recharge areas for the remainder of the year. A physiographic similarity exists between the depressions described by Meyboom and those observed at observation points E-114d, W-20, and on traverses W-27 and W-43. The similarity suggests that the depressions at E-114d, W-20, W-27, and W-43 are of the type which are discharge locations for part of the year and recharge locations for the remainder of the year. This is supported by the observation that no closed depressions were observed which definitely indicated a relative deficiency of water.

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*Conductivity in micromhos percentimeter x 0.7 $\approx$ total dissolved solids.

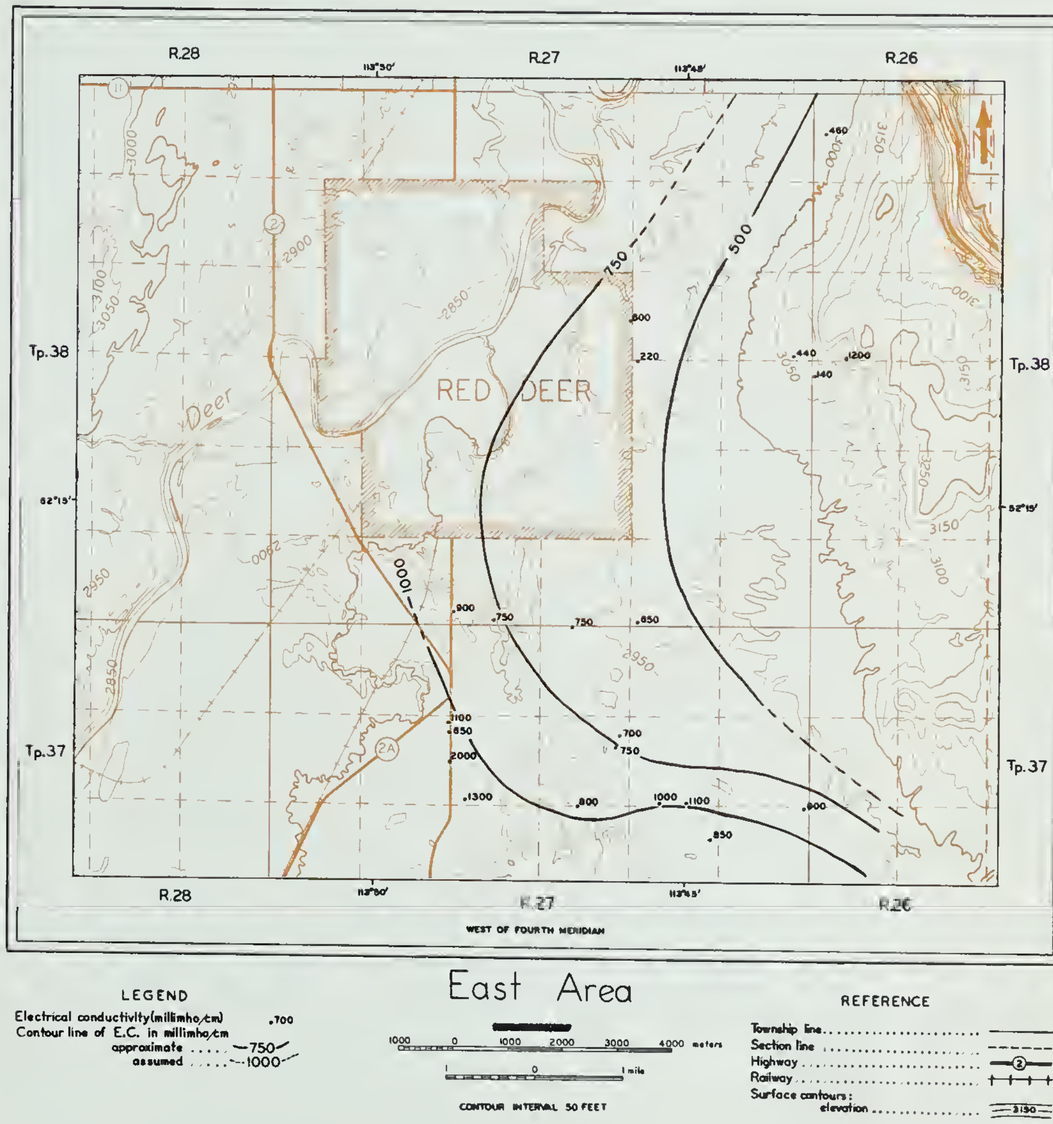


Figure 12. East area: Map showing areal distribution of the electrical conductivity of surface waters, September 24, 1966, 24 days after the last rain

An assessment of a closed depression based only on the feature itself is difficult. The depressions are best interpreted in light of the prevailing conditions in the general area. If a definite answer is required for a specific closed depression, then a thorough investigation of that depression should be carried out. However, for general mapping the interpretation, if not conclusive, should be suggested, but detailed investigation should not generally be carried out.

j) Locations at which surface materials are less resistant to surface erosion.

-gullies - A gully is a linear depression having steep slopes sharply delineated at their upper limits, one to several meters in depth with a similar width between the upper slope limits, which has formed as a result of running water. Plate X shows the gully at E-1 (a-9). The gullies observed are usually at the most a few hundred meters in length. The headward parts of the gullies are the most pronounced. Downstream the feature is less pronounced and finally ceases to exist.

Ten gullies were observed in the two areas of study (Figs. 8a and 8b). The gullies were observed on the steep slope of the highlands, in most cases toward the base of the slope. The gullies at W-31, W-36, W-44b, and W-102b had either a spring or a seepage associated with their headward region. Gullies at E-1 (a-9), E-98a, E-140d, and W-130 were associated with damp patches either in the gully itself or on the adjacent land surface.

The association of gullies with some points of relative surplus of water seems to agree with the idea put forth by Tóth (1966b). He suggested that at locations with soft and permeable pockets of surface material, and at which a continuous outflow of groundwater occurs, the ground is more vulnerable to surface erosion than adjacent locations where the above conditions do not exist. This is conceivably the case at the locations where seepages and springs are present.

At locations in which only indications of groundwater discharge are associated with the gullies, it is possible that the gully and the point of discharge are

Photograph showing the gully at E-1 (a-9).

PLATE X

related, due to either or both of the following conditions.

The first condition occurs if the outflow of groundwater is intermittent. The best example of this condition is when a spring or a seepage is present only in the springtime. This could result from the excess of groundwater in the discharge area because of the ground being frozen through the winter and the lack of transpiration. If during this time any excessive overland flow occurs, a gully could be started in the manner previously discussed. Once the "summer equilibrium" is reached, presence of the spring or seepage would no longer be evident and the only indications of groundwater discharge would be damp soil, salt precipitates, or some other associated discharge phenomenon.

The second condition whereby a gully could originate in association with indications of groundwater discharge occurs if an increase in permeability were to be associated with the damp soil. Because of larger permeability, it is possible that the forces holding the soil particles together are less than in the adjacent lower-permeability areas. Consequently, during the periods of excessive runoff, gullies will be formed associated with the damp patches. It is also very likely that this relationship could be the reason for the formation of gullies accompanying points of a continuous outflow of groundwater.

In cases where gullies are associated with points of groundwater discharge, the resulting increase in erodability of surface materials may be the result of a neutral stress caused by surfaceward-moving groundwater (Broscoe, personal communication, 1967). If the surface material and the discharge of groundwater are such that quick conditions result, and if this occurs on a slope, then a gully may originate from the downslope movement of the viscous fluid due to the quick condition. If, on the other hand, the discharge of groundwater and the local geologic conditions are such that a quick condition does not result, then increased erodability of the surface material may still result. In this case, there would be a decrease in the strength of the surface material, due to neutral stresses resulting from surfaceward-moving groundwater.

It is not intended to imply that gullies form as a result of groundwater alone. Their formation is believed to be caused by an interrelationship between surface water and groundwater, where they occur together.

Even though gullies do form in the absence of groundwater discharge, gullies are still useful features in mapping groundwater because they are usually easily observed on aerial photographs, and there is a good probability that there will be some phenomena related to groundwater discharge.

-meanders - The departure of the meander configuration from a sinusoidal pattern is a result of inhomogeneities in the erodability of the stream bank. When a stream meanders in a uniform material, the meanders are regular and they move downstream in an orderly manner. When the material is inhomogeneous, the meanders deviate from a regular pattern.

On the outside of several meanders along the Medicine River, springs and seepages were observed. The rates of discharge of the springs and seepages were small, generally less than a few liters per minute. Springs and seepages occurred on the outside of almost every meander along that portion of the river where points of discharge were looked for from the river.

Because the meander pattern of the Medicine River is very irregular, it is inferred that there is considerable inhomogeneity in the material being eroded. The presence of groundwater discharge at several meanders suggests that the inhomogeneity in the erodability of the bank may be related to either the presence of springs and seepages, or to conditions favoring groundwater discharge, that is, increased permeability.

The importance of meanders in groundwater mapping is much the same as for gullies. This is because the principles involved are the same.

3. Interpretation of Groundwater Flow

3.1 Distribution of Water Quality

To determine groundwater movement from only naturally occurring surficial features, the collection of water samples for chemical analysis is possible only from the following sources:

i) groundwater discharged at springs;

ii) subsurface waters encountered in shallow auger holes;

iii) surface waters where there are indications of groundwater discharge;

iv) surface waters where there are no indications of groundwater discharge.

a) East area

In the east area, both field and laboratory methods were used to determine the chemical quality of the waters sampled. A comparison of results using the two methods for the same waters is given in Table 2. The results for the most part are comparable.

Figure 13 is a map showing the distribution of the total dissolved solids in all waters tested in the east area. This distribution represents water samples obtained from the land surface, or immediately below it. From the distribution, it can be seen that waters with low total dissolved solids are found associated with the major highlands and with the local topographically high areas east and south of the city of Red Deer, as well as adjacent to the Red Deer River Valley. Waters with higher total dissolved solids are found in the southeast and southwest corners of the area studied. In each of the latter locations, total dissolved solids are recorded between 1,000 and 1,500 ppm. In an area east of the city, waters with total dissolved solids in excess of 900 ppm can be expected.

It is possible to group the waters from springs, seepages, and auger holes into four main types of water on a scatter diagram. The division of analysis is based on the percentage of sodium plus potassium of the total cations, and the percentage of bicarbonate plus carbonate of the total anions. The four types of waters indicated in figure 14 are as follows:

Table 2. A comparison between the results of chemical analysis by field methods and laboratory methods

Obs. Pt. No.	Date sampled	T.D.S. (ppm)	Na+K Per cent of total cations	HCO_3 $+CO_3$ Per cent of total anions	SO_4 Per cent of total anions	Remarks
E-1 (f-1)	7/17/66	*600	37	71	20	Auger hole
	8/10/66	†490	43	76	21	
E-97a	7/17/66	*800	64	67	28	Auger hole
	8/10/66	†708	65	73	25	
	8/10/66	†666	58	73	25	
E-141e	8/10/66	*700	37	70	25	Auger hole
	8/10/66	†796	43	79	20	
E-181d	8/10/66	*900	19	48	48	Auger hole
	8/10/66	†1016	26	42	57	
E-208	8/10/66	*500	6	85	8	Seepage
	8/10/66	†326	15	89	9	

*Analysis by field methods; total dissolved solids determined in field from conductivity reading (E.C. in micromhos/cm x .7 $\approx$ ppm; this was then rounded off to the nearest 100).

†Analysis by Provincial Analyst using laboratory methods.

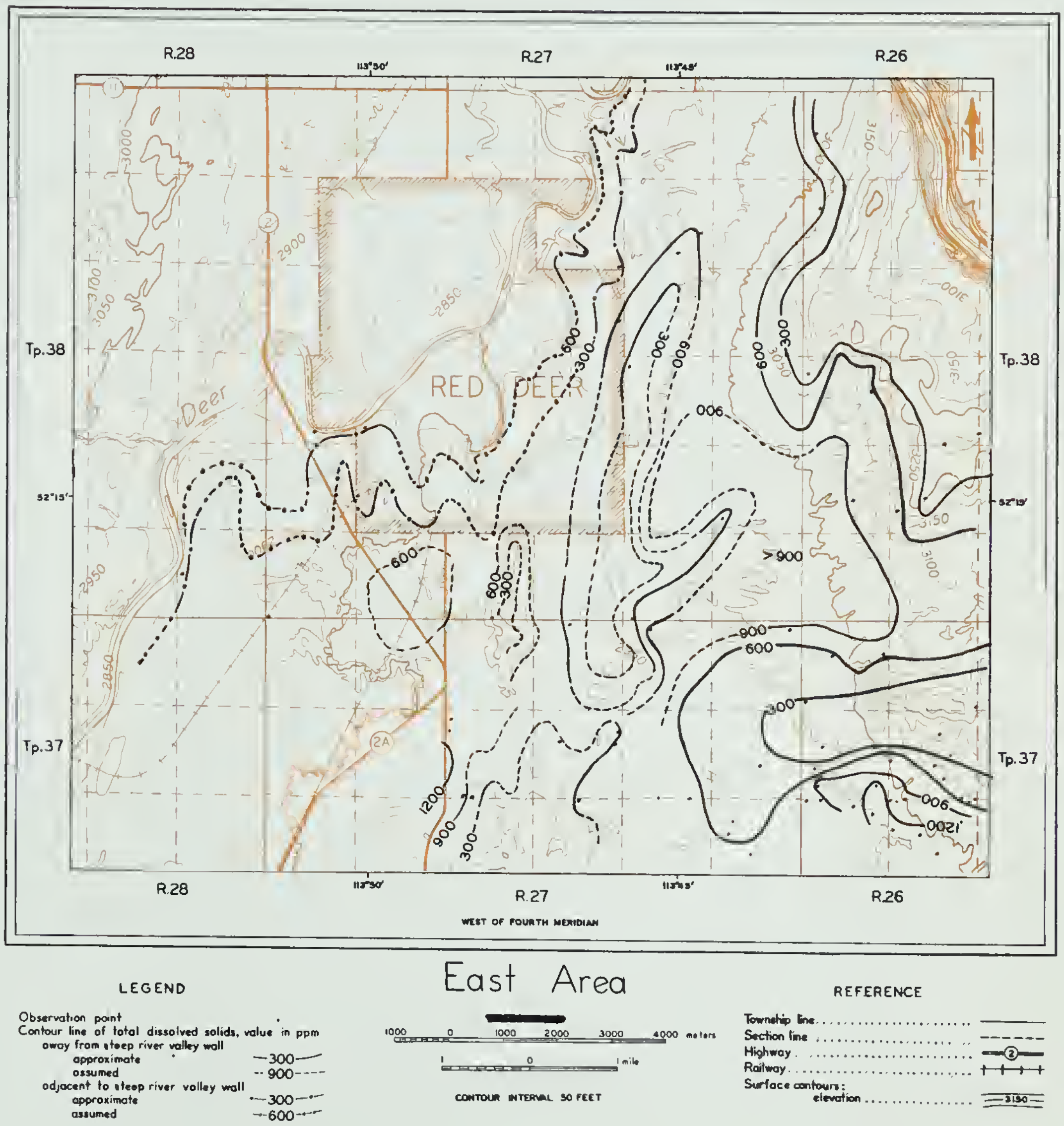
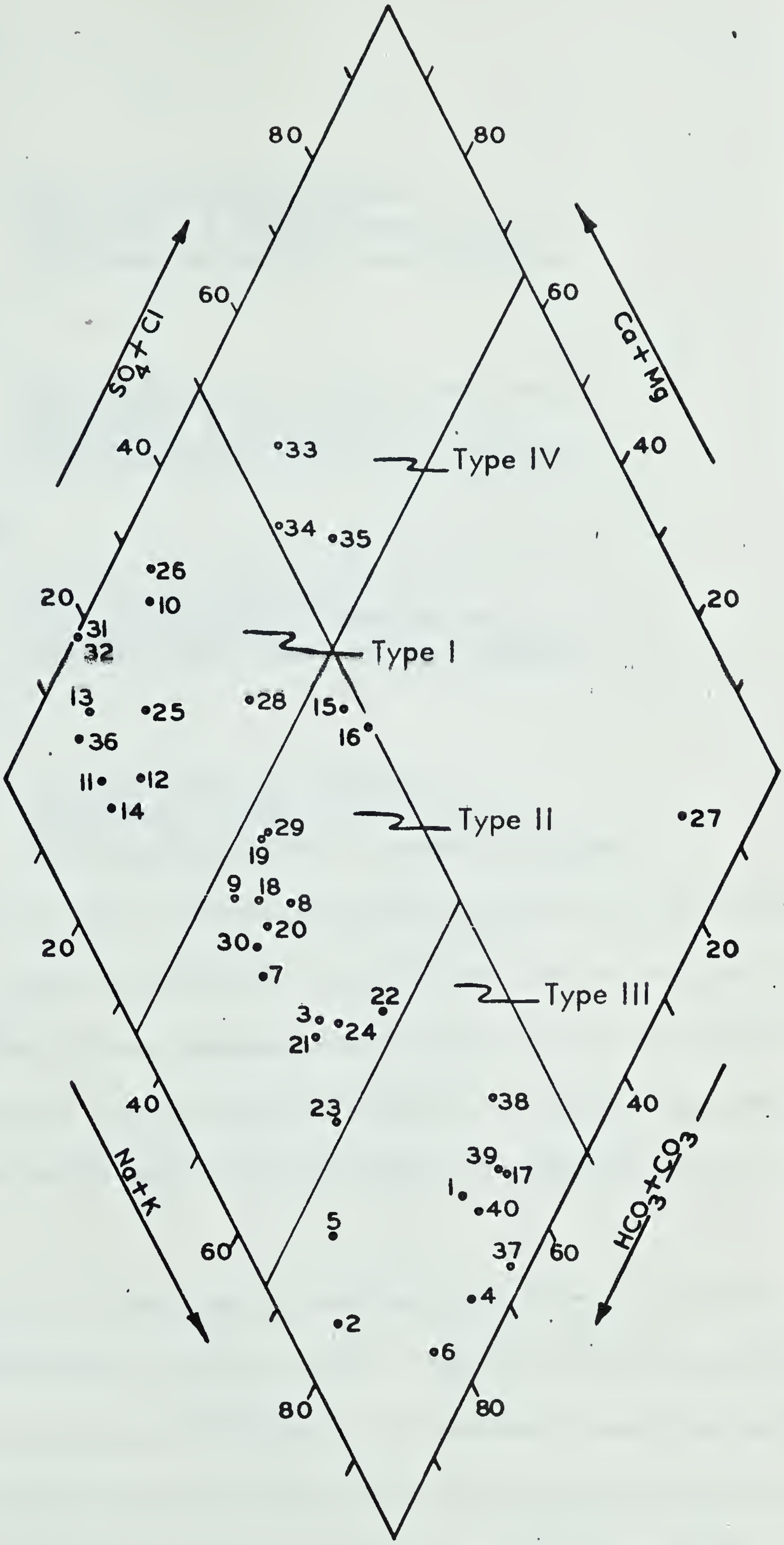


Figure 13. East area: Map showing areal distribution of total dissolved solids (in ppm) of waters sampled on and near the land surface

No.Obs.Pt.	No.Obs.Pt.
1 E-1(d-3)	21 E-47a
2 E-1(e-6)	22 E-97a
3 E-1(g-4)	23 E-97a
4 E-61a	24 E-97a
5 E-104a	25 E-108e
6 E-104a	26 E-114d
7 E-117c	27 E-114d
8 E-118a	28 E-141c
9 E-132a	29 E-141e
10 E-144b	30 E-141e
11 E-147e	31 E-147c
12 E-202	32 E-147c



13 E-208	33 E-181d
14 E-208	34 E-181d
15 E-210	34 E-181d
16 E-210	36 E-196c
17 E-1(c-10c)	37 E-1(c-10c)
18 E-1(f-1)	38 E-1(a-1)
19 E-1(f-1)	39 E-1(d-1)
20 E-1(f-1)	40 E-1(d-1)

Per Cent of Total Cation or Anion Equivalents Per Million

Figure 14. East area: Scatter diagram showing the four main types of water quality of subsurface waters sampled

Type I

$Na+K < 33\%$ of total cations
$HCO_3+CO_3 > 50\%$ of total anions
Total dissolved solids - average 500 ppm.

Type II

$Na+K > 33\%$ but $< 67\%$ of total cations
$HCO_3+CO_3 > 50\%$ of total anions
Total dissolved solids - average 600 ppm.

Type III

$Na+K > 67\%$ of total cations
$HCO_3+CO_3 > 50\%$ of total anions
Total dissolved solids - average 900 ppm.

Type IV

$Na+K < 33\%$ of total cations
$HCO_3+CO_3 < 50\%$ of total anions
Total dissolved solids - average 1,040 ppm.

The fourth type of water is based upon three samples from the same observation point. However, the waters analysed were very different from any analyses in the previous types. Therefore, these analyses were separated from the other types of water by arbitrary limits. Figure 15 is a pattern diagram showing the average value and range of total dissolved solids and of each set of elements for the waters grouped within each type of water.

Figure 16 is a map showing the distribution of the four types of water. Type I waters are interpreted as "young waters". They have a high percentage of Ca+Mg, and a high percentage of HCO_3+CO_3. These waters were obtained from auger holes in closed depressions in both local and regionally high depressions, from auger holes in lower land associated with the highs, and from springs and seepages along the Red Deer River valley bank. The waters represent short durations of flow under the land surface, as is indicated by the low total dissolved solids and the calcium plus magnesium bicarbonate composition.

The samples for Type II waters were collected from springs, seepages, and

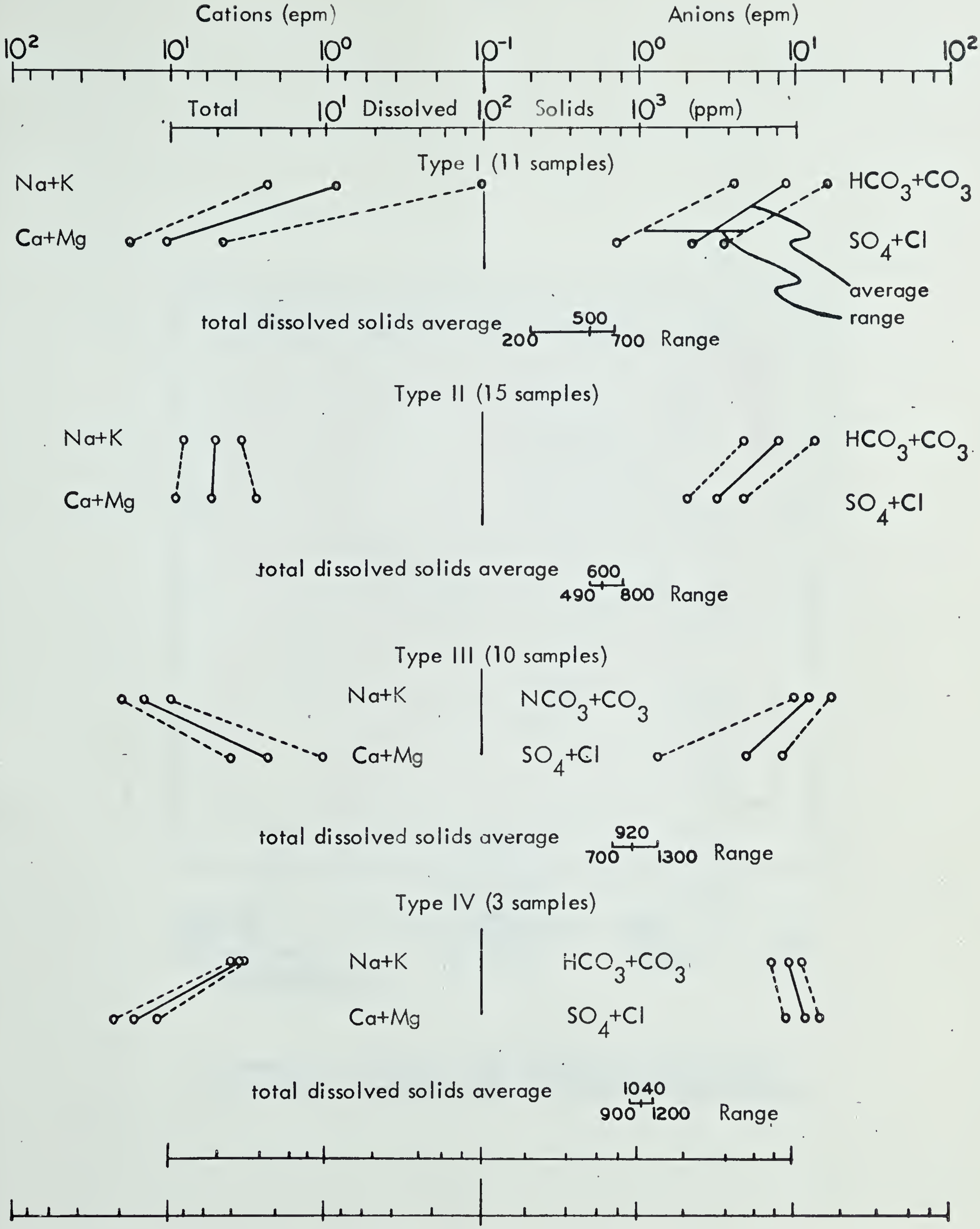


Figure 15. East area: Pattern diagram showing the four main chemical types of subsurface waters

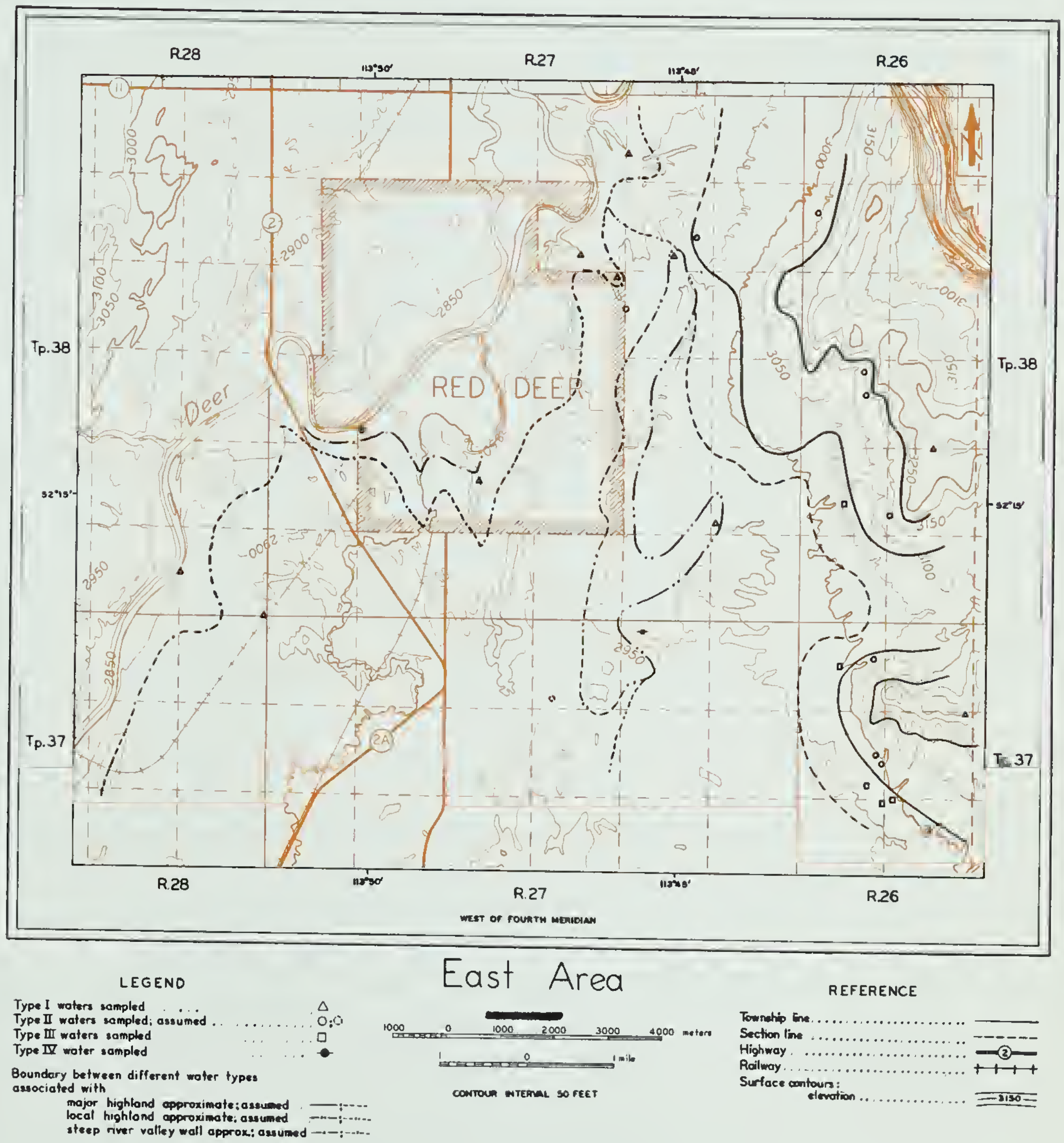


Figure 16. East area: Map showing areal distribution of the different chemical types of subsurface waters sampled

auger holes. The average total dissolved material in these waters is higher than that of Type I. Also, the Na+K composes a higher percentage of the cations. However, the percentage of HCO_3+CO_3 is unchanged from Type I. Type II waters are found farther from the highlands, adjacent to the Type I waters. The change in the chemical composition from Type I to Type II waters suggests a change in medium, due to the change in cations, as well as increased flow path of Type II over Type I.

Type III waters have higher total dissolved solids than either of the previous waters. The percentage of Na+K is also higher, but the HCO_3+CO_3 percentage remains unchanged. These waters are found only at the base of the steep highland slope and were obtained from springs, seepages, soap holes, and auger holes. The waters of this grouping have the longest flow path of the waters which outflow naturally onto the land surface in this area. Their increase in Na+K percentage suggests a longer interval of flow in the same medium through which the Type II waters flowed.

The fourth type of water (Type IV) has been based on one observation point only. However, the analysis of the three samples from this one point differ sufficiently from the analyses of waters in the other groupings to warrant separation of the water type. The per cent of sodium plus potassium of the Type IV waters is comparable to the "young waters" of Type I, but the per cent of sulphate plus chloride and the total dissolved solids are considerably higher than Type I waters. The higher total dissolved solids and per cent sulphate plus chloride suggests that this water has flow paths of longer duration than all the other waters sampled. If the water sampled is representative of a fourth type of water, and if the chemical quality of this water has resulted from a long duration of flow, then the high percentage of calcium plus magnesium suggests that the water toward the end of its flow path passes through a medium high in calcium and magnesium.

In summary, there is an increase in the average total dissolved solids through

all types of water from I to IV. Types I to III have the same percentage of HCO_3+CO_3 with an increasing percentage of Na+K. The fourth type has a low Na+K as well as a low HCO_3+CO_3 percentage.

b) West area

The distribution of the total dissolved solids for waters at or near the land surface in the west area is given in Figure 17. Waters with low total dissolved solids were taken from auger holes and springs on the regional highland and adjacent steep slopes. Waters with low total dissolved solids are also associated with the sand dune area by the Medicine River. The water samples from the dune area came from springs, seepages, and auger holes. Water samples obtained from shallow auger holes in the area between the sand dunes and the base of the steep highland slope were analysed as having between 1,600 and 10,000 ppm total dissolved solids.

It is possible to outline four types of water quality on a scatter diagram (Fig. 18) in the same manner as for the east area. The four types of waters outlined are as follows:

Type V

$Na+K < 35\%$ of total cations
$HCO_3+CO_3 > 60\%$ of total anions
Total dissolved solids - average 383 ppm.

Type VI

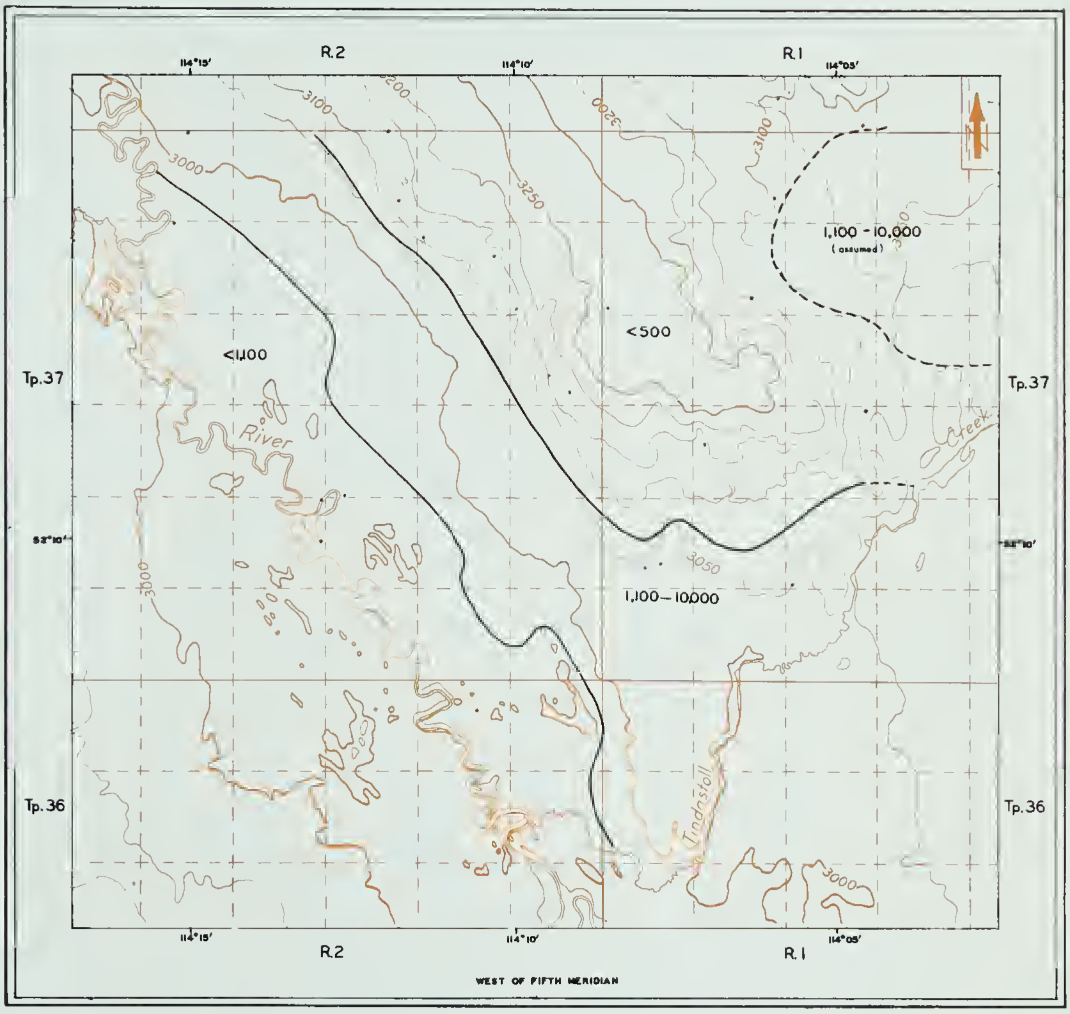
$35\% < Na+K < 80\%$ of total cations
$HCO_3+CO_3 > 80\%$ of total anions
Total dissolved solids - average 400 ppm.

Type VII

$Na+K < 25\%$ of total cations
$60\% > HCO_3+CO_3 > 10\%$ of total anions
Total dissolved solids - average 1,558 ppm.

Type VIII

$Na+K > 80\%$ of total cations
$50\% > HCO_3+CO_3 > 10\%$ of total anions
Total dissolved solids - average 5,059 ppm.



West Area

LEGEND

Observation point. . . . .

Total dissolved solids in ppm. 500

1000 0 1000 2000 3000 4000 meters

1 0 1 mile

CONTOUR INTERVAL 50 FEET

REFERENCE

Township line. . . . .

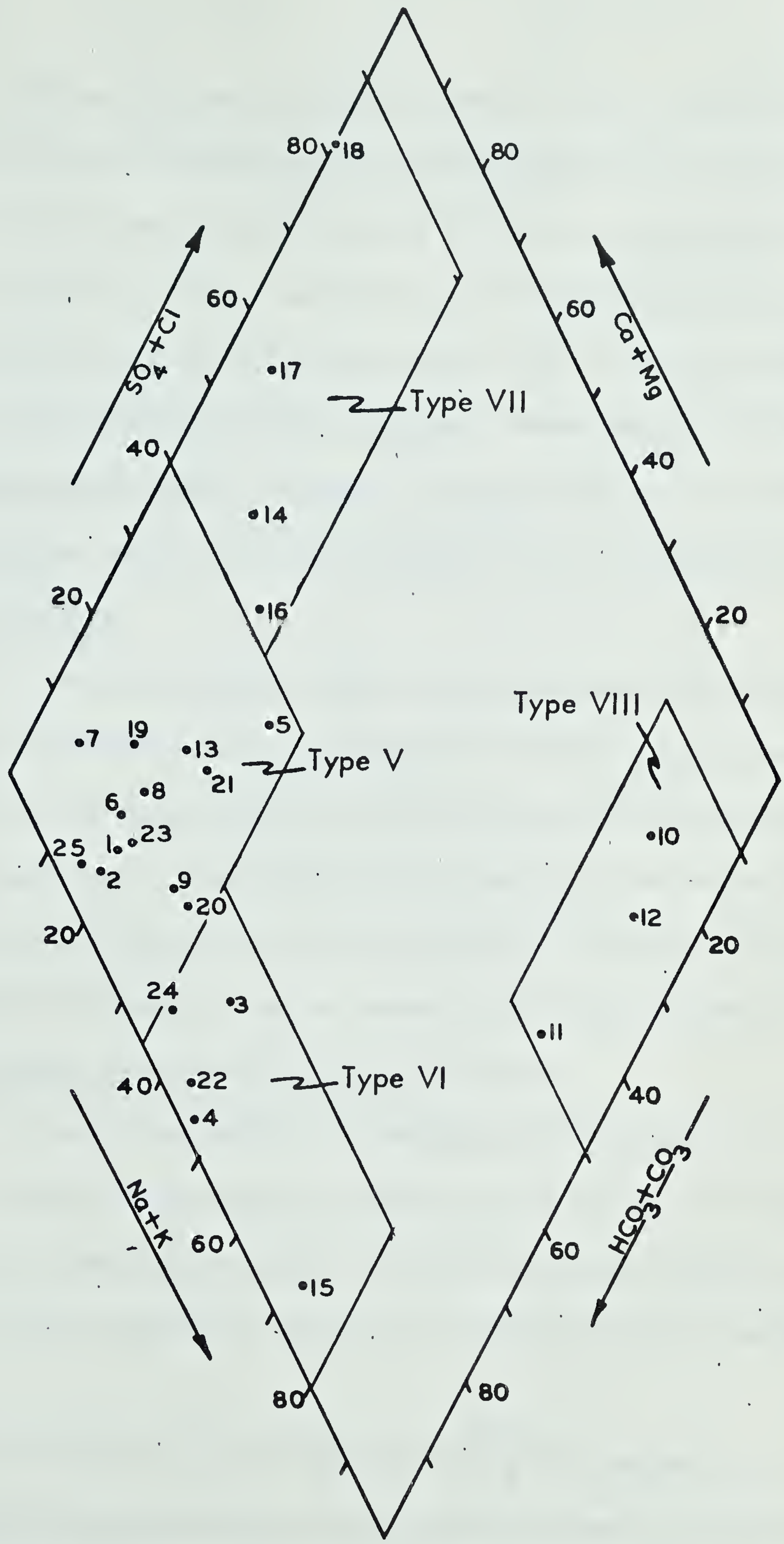
Section line . . . .

Surface contours:
elevation 3150

Figure 17. West area: Map showing areal distribution of total dissolved solids (in ppm) of waters sampled

No.Obs.Pt.	
1	W-1
2	W-3
3	W-11
4	W-12
5	W-19
6	W-32
7	W-33
8	W-44b
9	W-55
10	W-60
11	W-67
12	W-67a
13	W-80

No.Obs.Pt.	
14	W-100
15	W-113
16	W-117
17	W-117
18	W-117
19	W-120
20	W-121
21	W-122
22	W-140
23	W-150
24	W-151
25	W-152



Per Cent of Total Cation or Anion Equivalents Per Million

Figure 18. West area: Scatter diagram showing the four main types of water quality sampled

Figure 19 is a pattern diagram showing the average value and range of total dissolved solids and of each set of elements for the waters grouped within each type of water.

Figure 20 is a map showing the areal distribution of the different types of waters. Type V waters are low in total dissolved solids. They are mainly $(Ca+Mg)(HCO_3+CO_3)$ waters. These waters are typical "young waters"; that is, they are waters which have been under the land surface for a short duration. Water samples included in this grouping were collected from springs, seepages, and auger holes on the southern three-quarters of the highland, and in the local topographic lows of the sand dune area adjacent to the Medicine River.

Type VI waters are slightly higher in average total dissolved solids than Type V waters; they are for the most part of $(Ca+Mg)(Na+K)(HCO_3+CO_3)$ composition. They are found only on the steep slopes of the highland toward the northern boundary of the area. The samples were collected from springs, seepages, and auger holes. All the points of sampling are associated with a slightly lower surface slope than is present to the south, and this is thought to be the reason for the slight difference in chemical composition between the waters of Type V and Type VI.

Type VII waters are mainly of $(Ca+Mg)(SO_4+Cl)$ composition. The average total dissolved solids is more than triple that of Type VI waters. The higher sulphate content suggests a longer flow system. The fact that the two locations at which these water samples were collected are close to the Medicine River also suggests a long flow path.

Type VIII waters are mainly of $(Na+K)(SO_4+Cl)$ composition. All of the samples were collected from auger holes in less-fertile soil areas in the almost flat area extending from the base of the steep slope of the highland. The very high total dissolved solids, relative to the rest of the waters sampled, indicates a long interval of time under the land surface. The long interval of time for the water to be under the land surface can probably be attributed to the presence of a very low surface slope

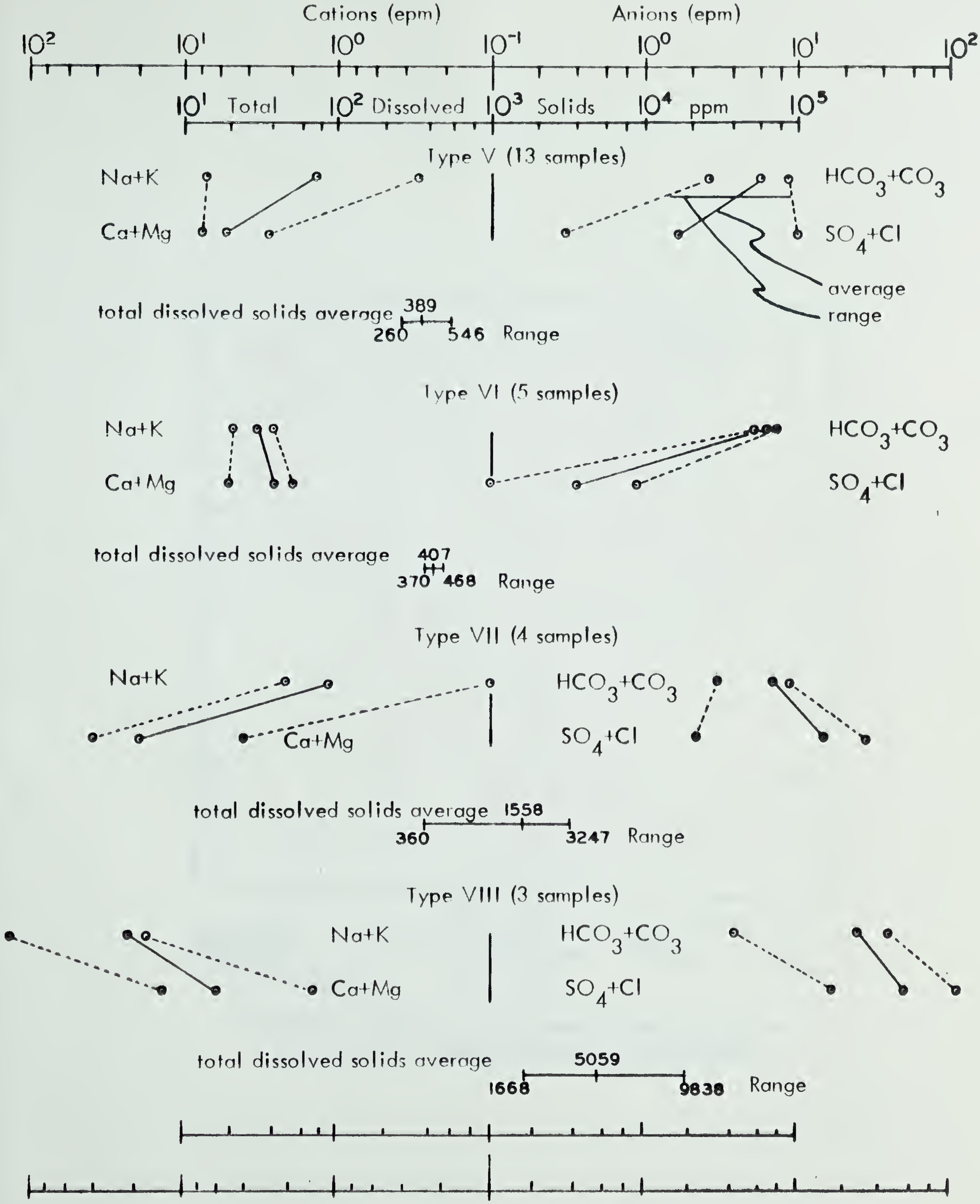


Figure 19. West area: Pattern diagram showing the four main chemical types of waters sampled

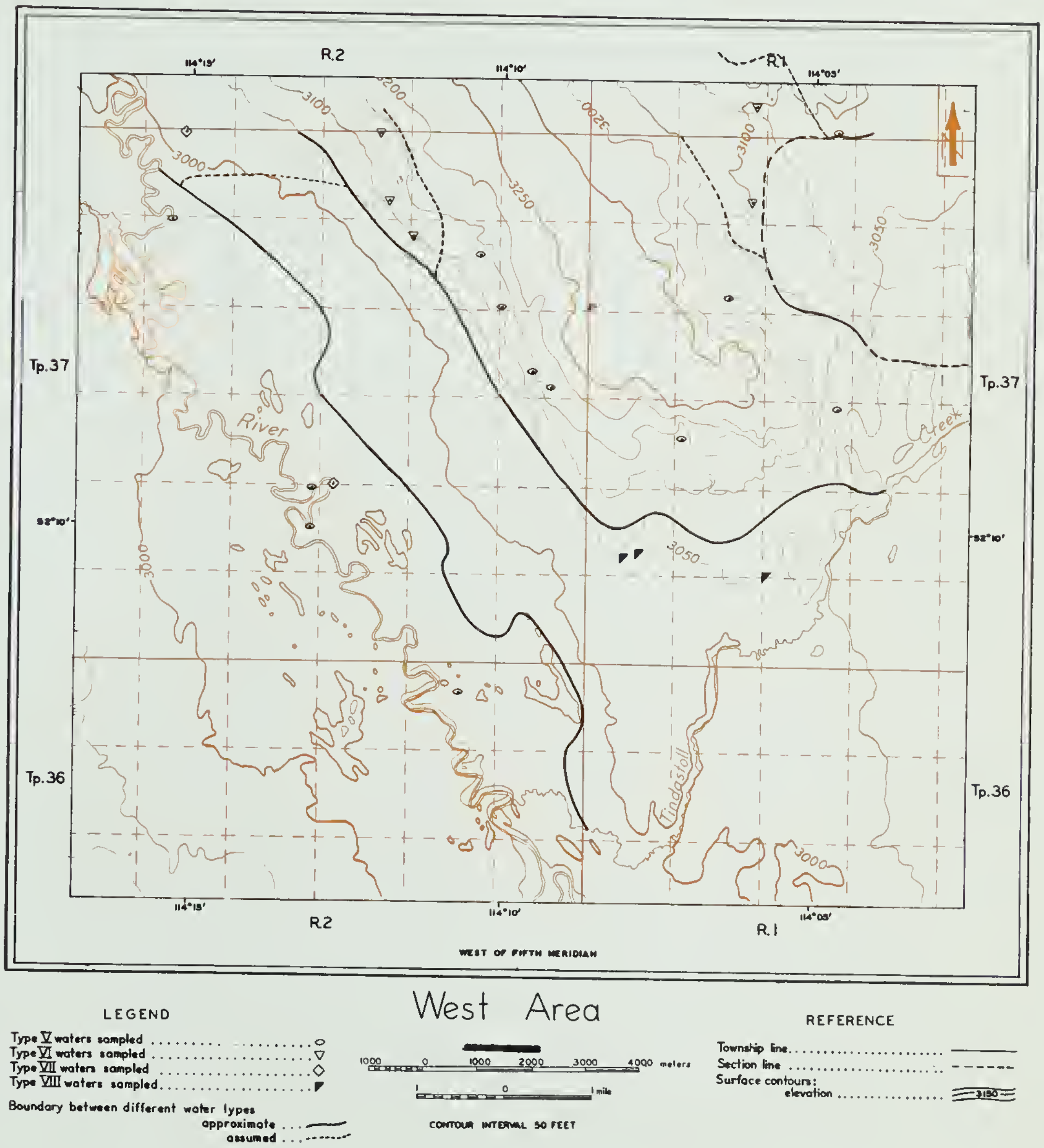


Figure 20. West area: Map showing areal distribution of the different chemical types of water sampled

and a low-permeability medium through which flow is taking place.

As in the east area, there is an increase in total dissolved solids from Type V through to Type VIII. Type V and VI waters appear to be restricted to sandier media, Type VI waters resulting from a longer duration of flow. Type VII and VIII waters flow through media composed in part of lake deposits. Of these two latter types of waters, Type VIII appears to represent the longer duration of flow.

3.2 Groundwater Levels

The groundwater level is that position in space to which groundwater in contact with the atmosphere will rise under its natural hydraulic head. In studies wherein man-made features are used to obtain information, the groundwater levels are obtained mainly from the level to which water will rise in a well. In this study, the groundwater levels were obtained from naturally occurring phenomena. In situations of unconfined groundwater flow, the determined groundwater level, based upon naturally occurring surficial features, is the water table.

The water table represents the upper surface of the groundwater region and is the surface in an unconfined groundwater flow region along which the hydraulic head is equal to atmospheric pressure. The gradient of the water table gives the rate of change of groundwater potential along the upper surface of the groundwater region. From the gradient of the water table, it is possible to determine the general direction of groundwater flow only, and not the path of flow of groundwater within the groundwater region.

In areas in which the water table is a subdued replica of the topography, the water table can be approximated by the land surface. By the utilization of shallow auger holes encountering groundwater, as well as springs and seepages, a closer approximation of the water table is feasible. However, these points are generally so far apart that not much improvement on the initial approximation is made. If all the points indicating the proximity of groundwater to the land surface are also used,

an even better approximation of the water table is possible. The water table at locations having indications of groundwater near the land surface can be approximated by the land surface; in areas in which there is an absence of indications of groundwater close to the surface, the water table can be approximated to be at a depth of a least a few meters below the land surface. Figures 21a and 21b give the water-table map for the east and west areas, respectively, determined in the manner described in the preceding discussion.

A water-table map, when constructed from naturally occurring surficial features, is also a summary of the locations in which groundwaters are close to the land surface. In areas in which there are indications of groundwater close to the surface, the contour lines of the water table almost coincide with topographic contour lines of corresponding values. Where these two lines separate, with the water-table contour being upslope from the corresponding topographic contour, the groundwater is farther from the land surface. From figures 21a and 21b, it can be seen that generally the groundwater is close to the surface in relatively low topographic areas, and farther from the surface in relatively high topographic areas.

3.3 Distribution of Recharge and Discharge Areas

In an infinitely large area in which the land surface is horizontal, an equilibrium between the gains from precipitation and the losses from evapotranspiration by the groundwater region will result in the average position of the water table being a certain distance below the land surface. A change in this distance will only be brought about by changing the amount of precipitation or the amount of evapotranspiration. If the precipitation and evapotranspiration remain constant over the whole area, the depth to the water table will also remain constant for a uniform material.

When the land surface is not horizontal, and the evapotranspiration and precipitation are constant over the whole area, the water table will be at a shallower depth in the lowlands (than in the horizontal case), and at a greater depth in the

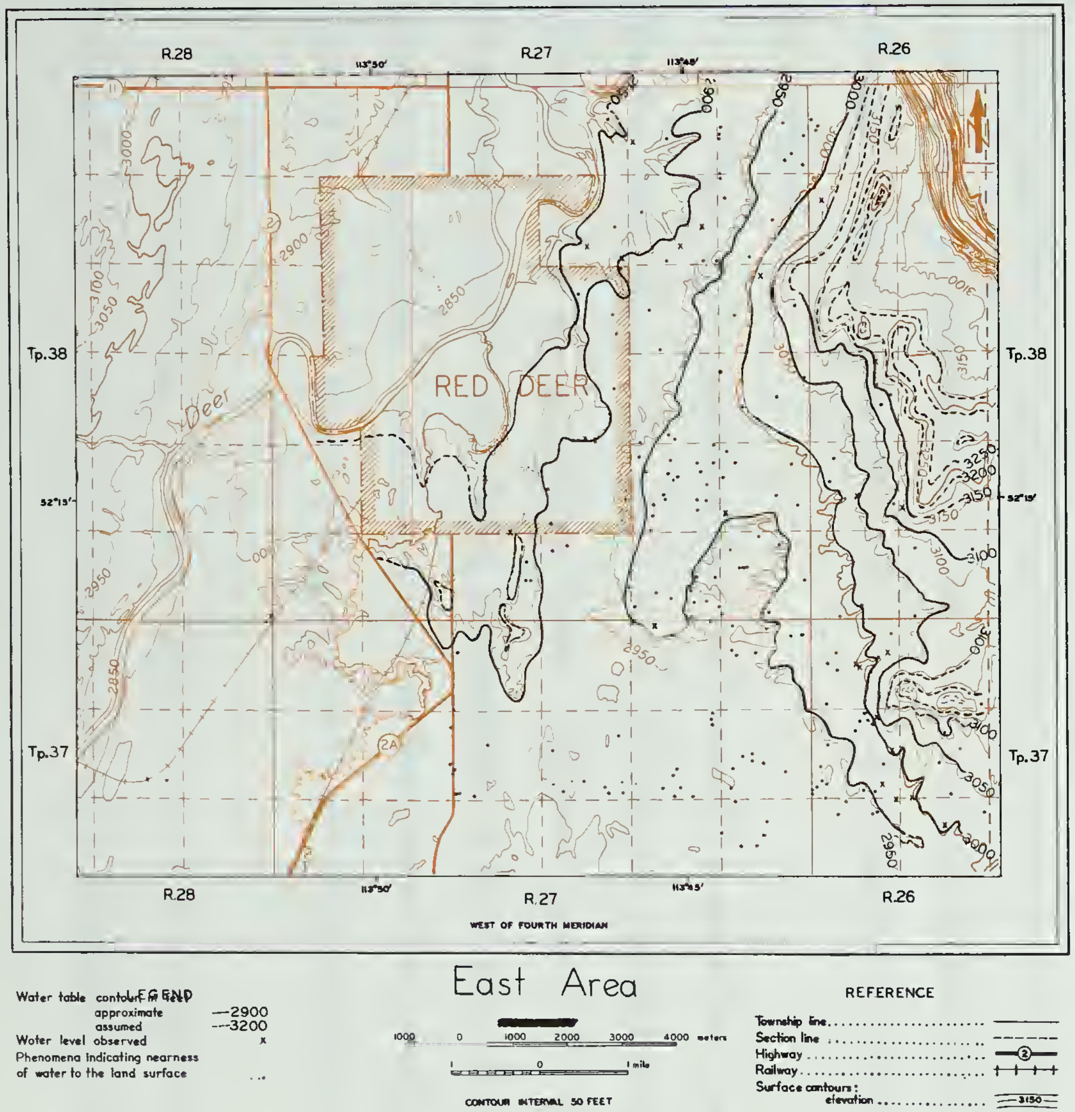


Figure 21a. East area: Water table map

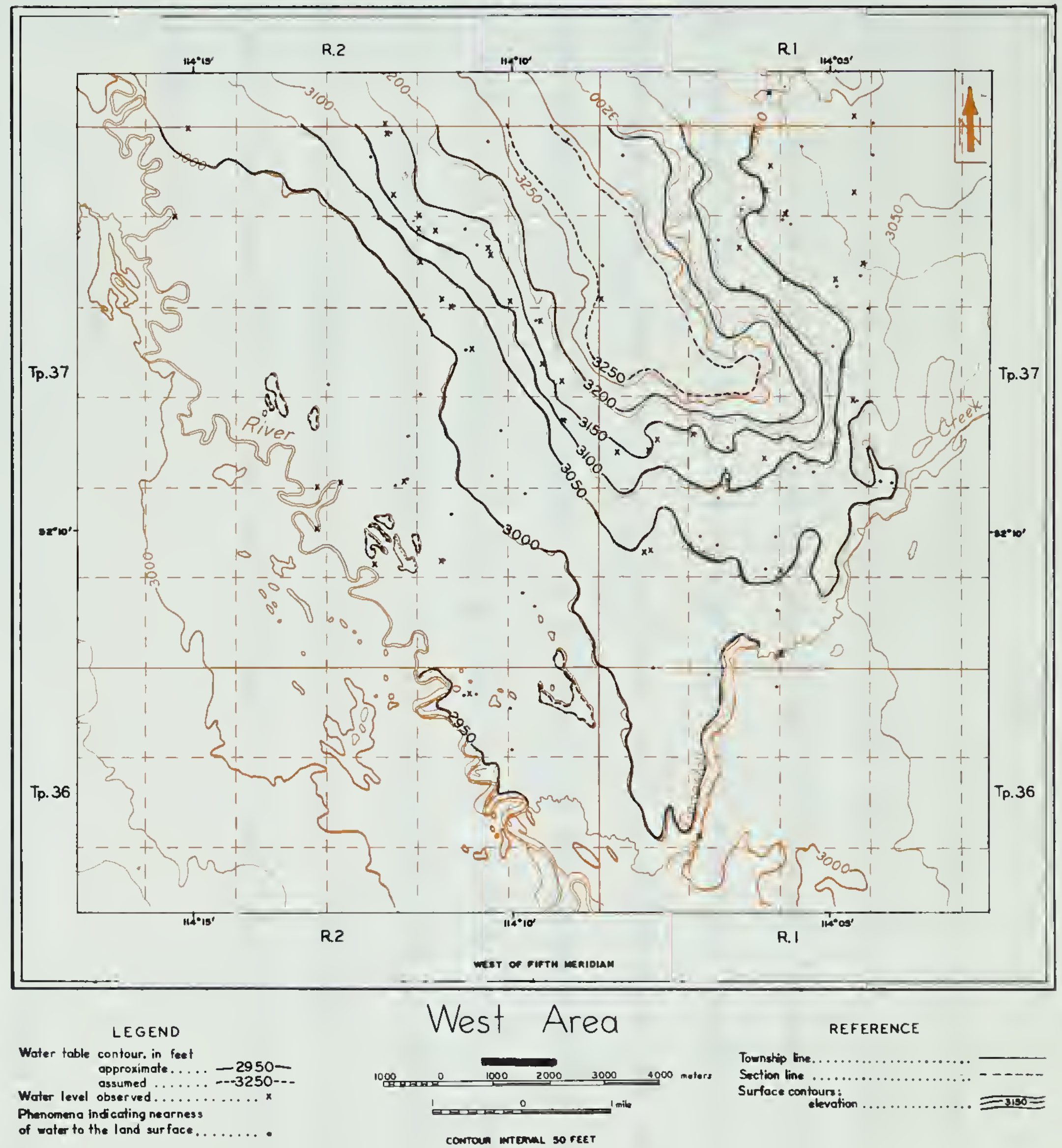


Figure 21b. West area: Water table map

highland (than in the horizontal case). These conditions result from the flow of groundwater from the higher land to the lower land as shown in figure 22.

On the basis of the results presented in the preceding paragraph, and shown in figure 22, in areas in which the groundwater is moving toward the surface (that is, discharge areas), there will be a surplus of water, relative to that which is derived from surface sources. The surplus is the result of the presence of groundwater. This is indicated by the water table being close to the land surface in unconfined systems. The recharge areas, on the other hand, will be areas with a deficiency of water, relative to that being supplied by surface sources. Therefore, on the basis of the nearness of the water table to the land surface, it is possible to outline the discharge and recharge areas.

a) East area

Figure 23a shows the distribution of groundwaters moving toward and away from the land surface. The areas outlined are of three types: first, groundwater mainly moving away from the land surface; second, groundwater moving away from the land surface in local topographically high lands, and moving toward the land surface in adjacent topographically low lands; and third, groundwater moving mainly toward the land surface.

There are three parts of the east area with groundwater moving mainly away from the land surface. The major part is the regional topographically high land four kilometers east of the city of Red Deer. This area serves as the main recharge area for the majority of the circulating groundwaters in the basin. Minor parts of the area wherein groundwater is moving away from the land surface are adjacent to the steep bank of the Red Deer River valley, and on local topographically high ridges south of the city.

Sand dunes, present within the area, are up to 10 meters in height with intervening low areas. The dunes are characterized by groundwater moving away from the

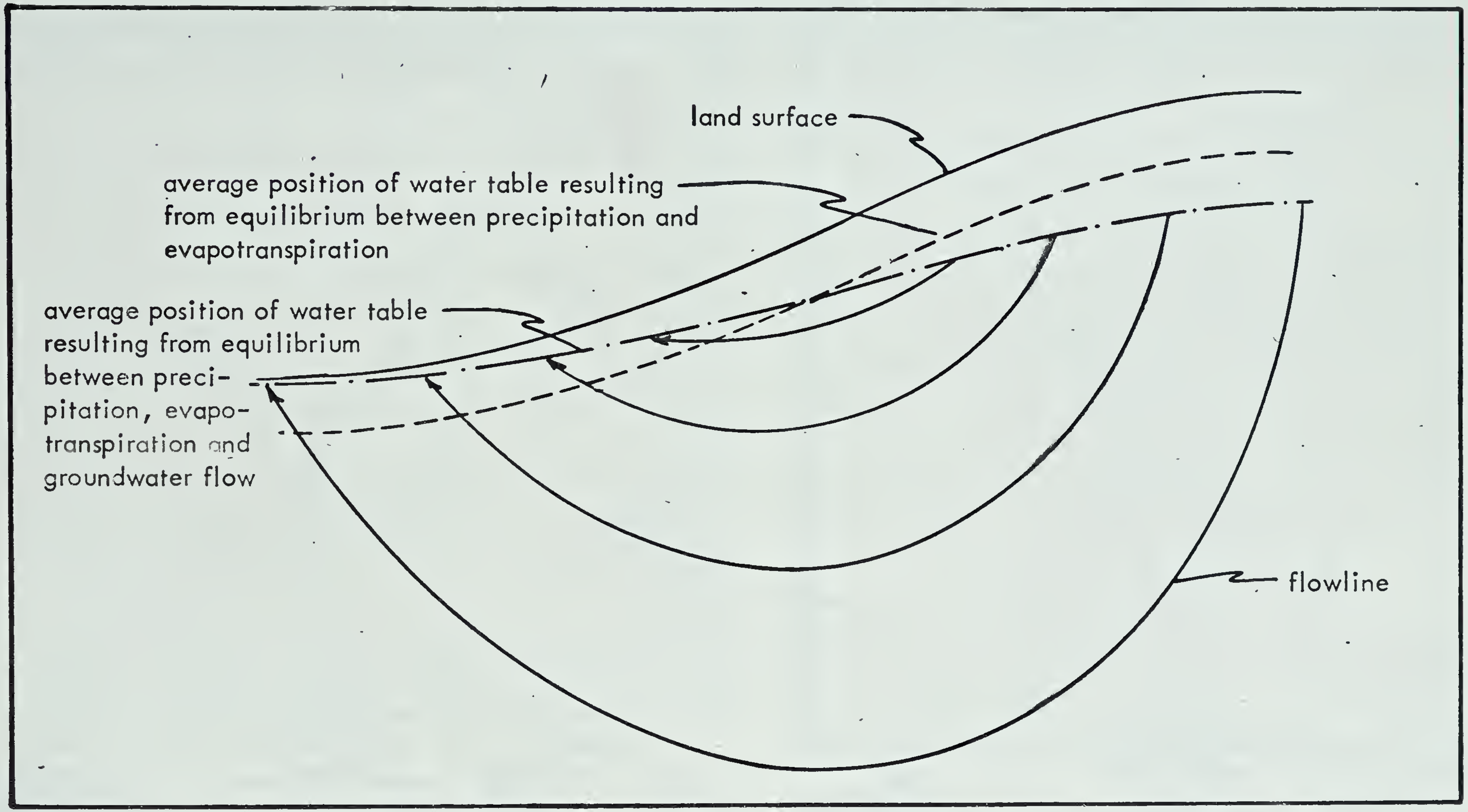


Figure 22. Diagrammatic representation of the average position of the water table as a result of groundwater flow

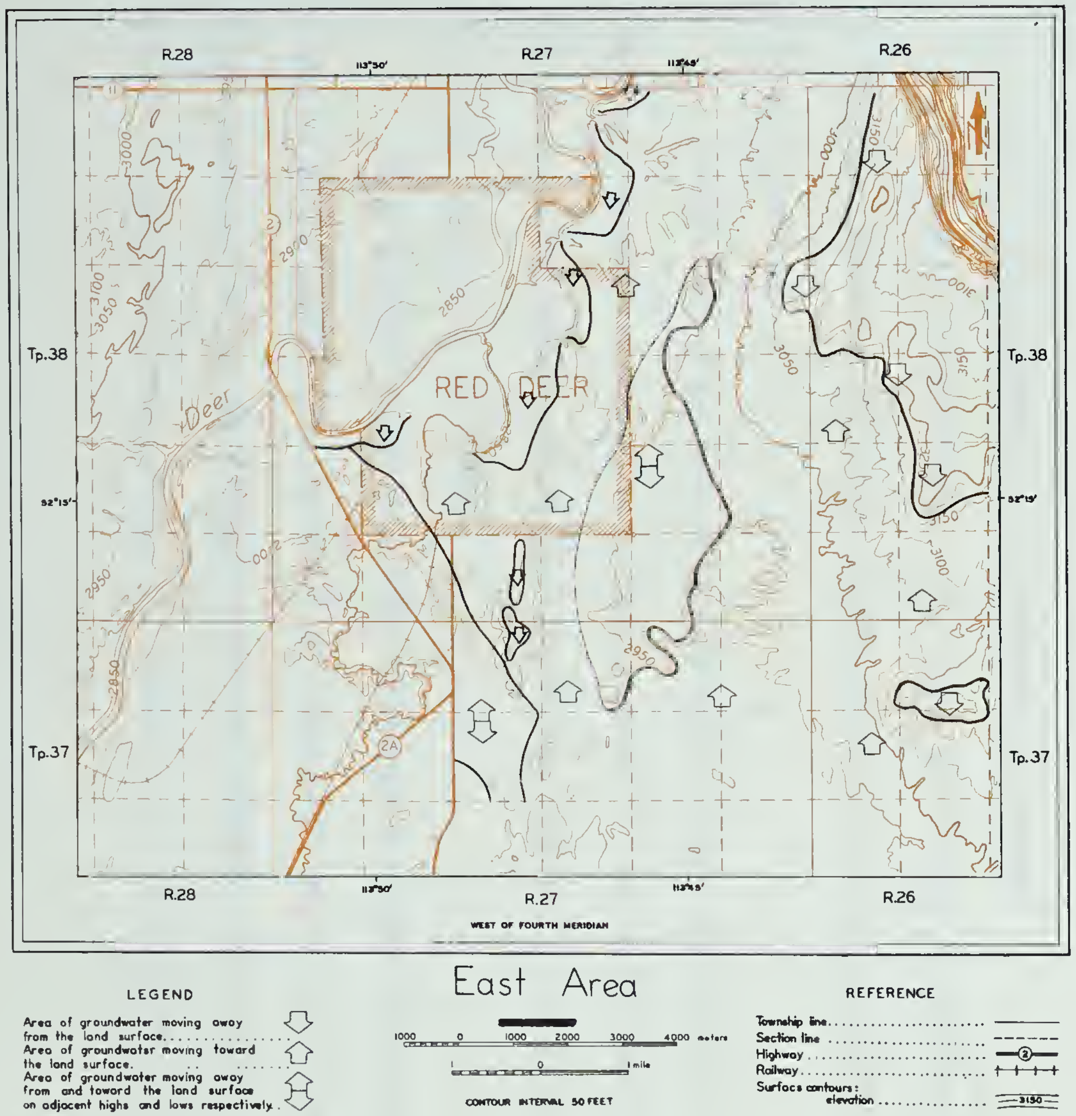


Figure 23a. East area: Areal distribution of the direction of groundwater movement relative to the land surface

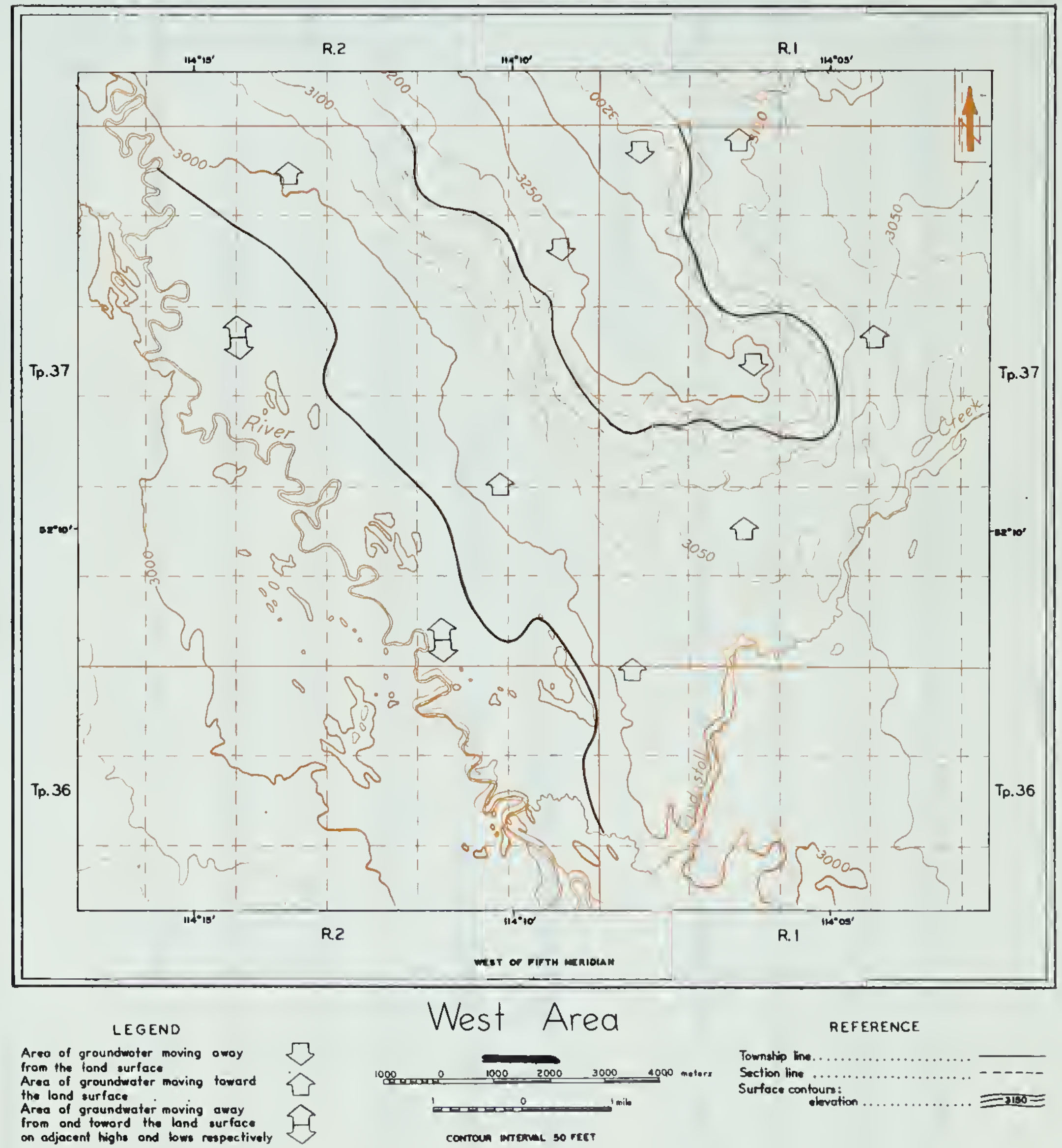


Figure 23b. West area: Areal distribution of the direction of groundwater movement relative to the land surface

land surface on their upper part, and toward the land surface in their lower parts.

The remainder of the east area is characterized by groundwater moving toward the land surface. The groundwater for the most part will be from the regional high, but in some cases there may be groundwater from adjacent local topographic highs.

b) West area

The distribution of groundwater moving toward and away from the land surface is shown in figure 23b. Groundwater is mainly moving away from the land surface over the majority of the regional topographically high area. The highland serves as the main source of waters being added to the circulating groundwater.

The sand dunes adjacent to the Medicine River are characterized by groundwater moving away from and toward the land surface in the same manner as the sand dunes of the east area.

The remainder of the west area is characterized by groundwater moving toward the land surface.

3.4 Interpretation of Groundwater Movement

In the two areas studied, the major part of the circulating groundwater is found in the flow systems commencing on the highest land and terminating in part on the adjacent lowlands.

In setting I (Fig. 6a), the major flow systems commence on the highlands and terminate in part on the adjacent lowland and in part in the Red Deer River valley. The rates of groundwater flow are high on the highland, but on the low slope of the lowlands circulation is slower.

Field evidence indicates that discharge is taking place across most of the expanse of the gently sloping lowland. However, close to the steep river bank, a small local system has developed due to the steepness of the bank. In this region there will be a deflection downward of the flowlines of the regional flow system (Fig. 24).

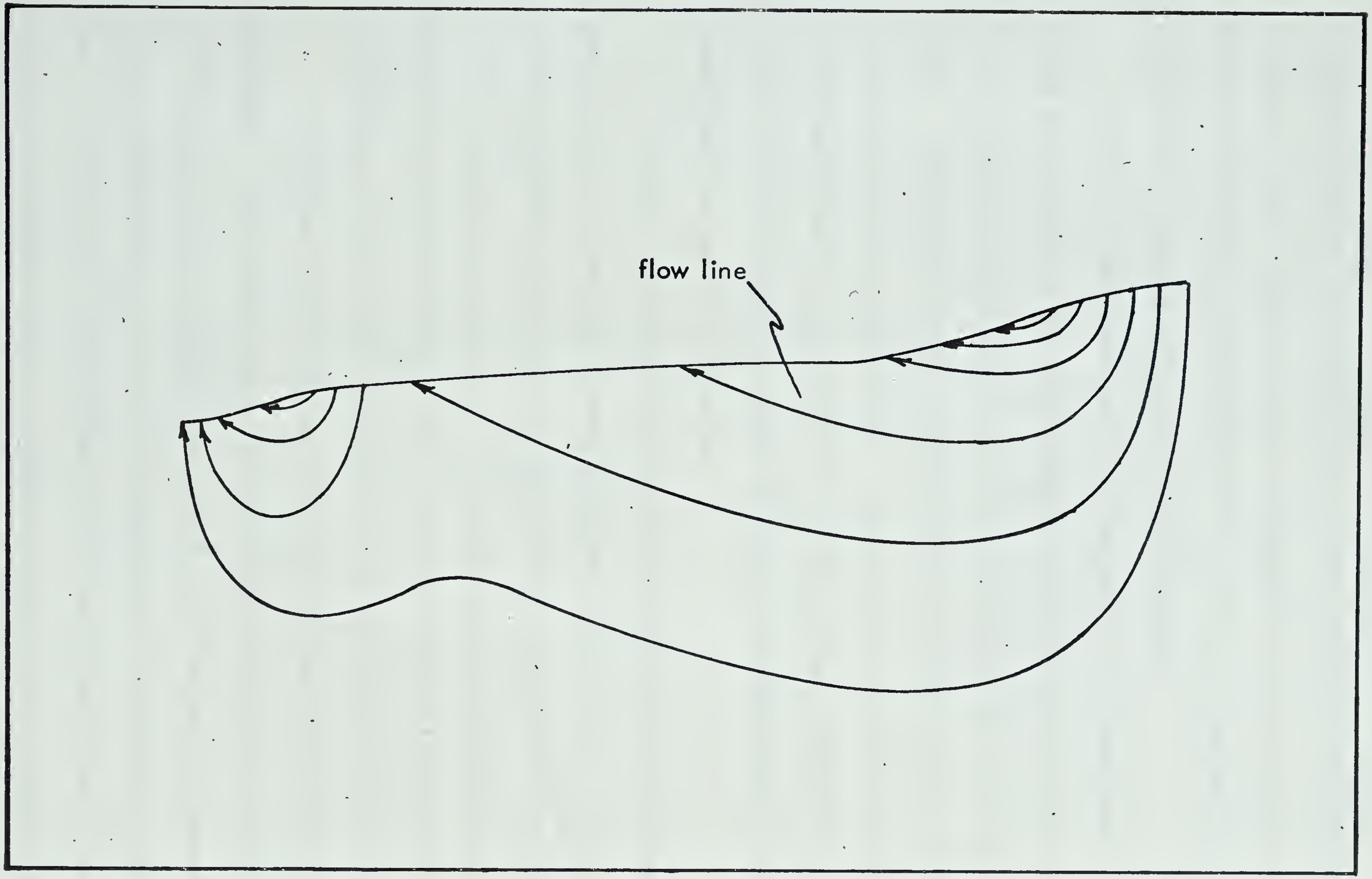


Figure 24. Diagrammatic hydraulic cross section with flow distribution similar to that which prevails parallel to maximum topographic gradient in setting I.

Setting II (Fig. 6a) has a more complex flow of groundwater. The major highland is still present, supplying the water and drive for the main groundwater flow system. However, there is at least one local topographic low and one local topographic high between the highland and the Red Deer River valley; consequently, very little of the water from the highland will reach the Red Deer River.

The sand dune areas have local topographic highs and lows. In the area east of Red Deer, the slope between the highland and the Red Deer River is in the order of 1 in 40 (0.025), and the local relief within the dune area can be up to seven or eight meters. Theoretically, under these conditions, the local systems could extend down to as much as a few hundred meters. However, due to limiting factors such as depth to the base of the major groundwater circulating system, anisotropicity, and nonuniformity of the local relief, the depth of the local systems would for the most part not extend below several 10's of meters.

The major flow systems starting on the highlands will be deflected for the most part as a result of the local systems associated with the dunes. Parts of the flow systems from the highland will be deflected down the broad, shallow linear depression east of the sand dune area; small parts will be deflected so that discharge will occur in deeper depressions of the dune area, other small parts will pass under the local systems to discharge in one or more of the low areas to the west of the dune area (Fig. 25).

Local flow systems are associated with north and south facing slopes on the highlands. Flow in these systems will be deflected westward, at least in part, because of the regional slope toward the Red Deer River. The most pronounced of these flow systems is associated with the south facing slope in the southeast corner of the mapped area. This flow system extends from the highland to the thalweg occupied by the unnamed creek which marks the southern boundary of part of the east area.

The major flow systems in the west area, as in the east area, commence on the regional highland. In setting III (Fig. 6b), sand dunes are present along the

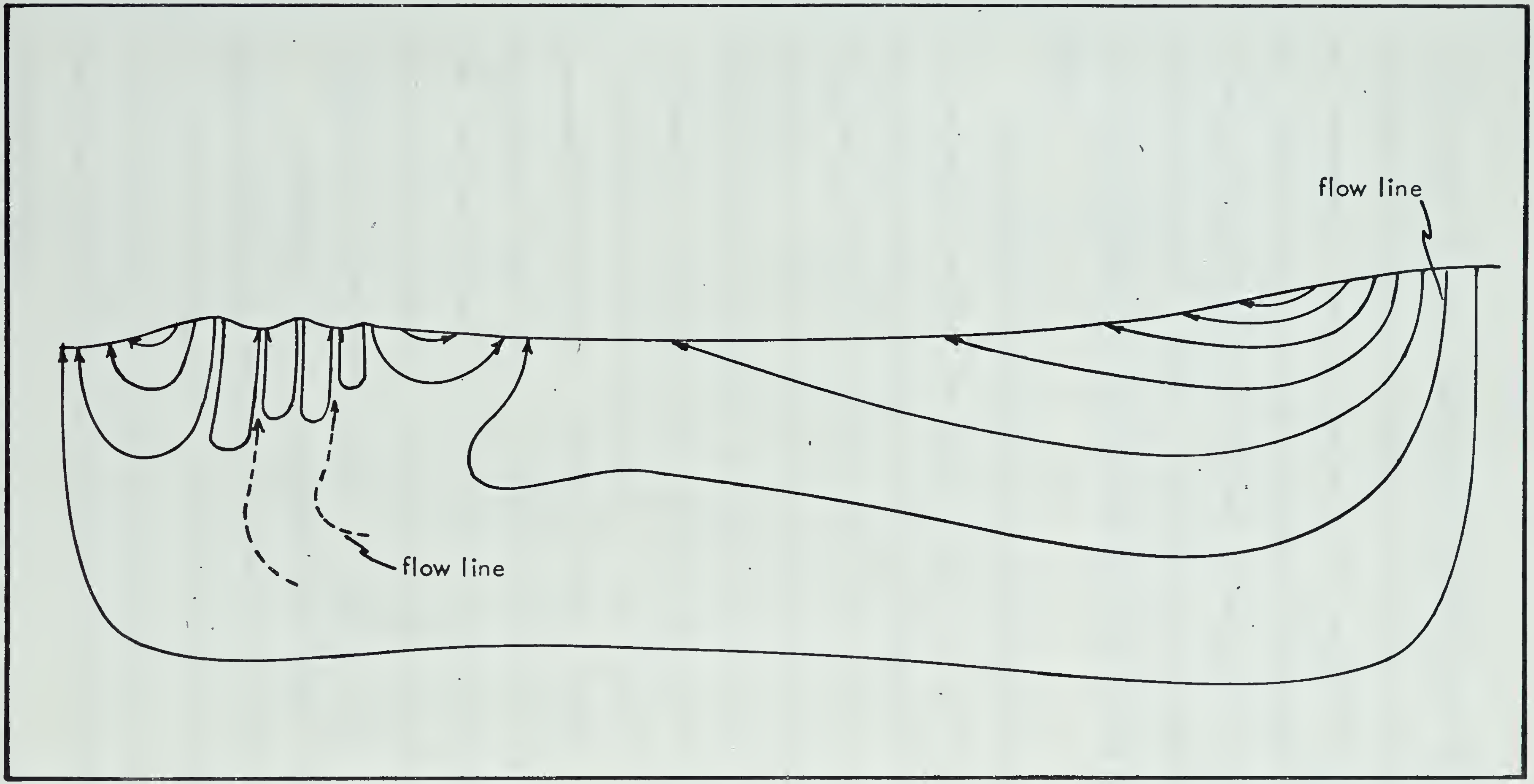


Figure 25. Diagrammatic hydraulic cross section with flow distribution similar to that which prevails parallel to maximum topographic gradient in setting II.

western edge of the gently sloping lowlands extending from the base of the steep slope of the highland. The dunes are comparable in size to those close to the city of Red Deer and, consequently, would be expected to have comparable associated local flow systems. Because of the flow systems associated with these dunes, the major flow systems of setting III, originating on the highland, discharge mainly in the lowland area east of the dunes (Fig. 26). However, small portions of the major flow systems may discharge in the deeper depressions in the dune area and in the thalweg occupied by the Medicine River.

The effect that the local flow systems associated with the dune area have on the discharge of the major flow systems is seen by the presence of an accumulation of peat at least a meter in thickness in the low area between the sand dunes and highlands. The peat area has several indications of high water levels, including the presence of hand-dug wells with water levels within a meter of the land surface. At the northern edge of setting III, the dunes are restricted to the west side of the Medicine River; consequently, no local flow systems restrict the flow of the regional flow system (Fig. 27) and there is no accumulation of peat. In the southern portion of setting III the groundwater flow is minimal. The flow which does take place is almost parallel to the sand dunes and, again, there is no significant accumulation of peat. Thus it can be seen that where the dunes are present and where significant amounts of groundwater are circulating, the effects of the local systems associated with the sand dunes perceptibly alter the pattern of discharge of the regional systems.

In setting IV, there are no important local systems. The flow systems from the highland discharge upon the lower part of the steep slope of the highland and upon the adjacent lowland (Fig. 28). Rates of flow associated with the highland are relatively high because of a favorable medium and high surface slopes, but rates of flow in the lowland are low, due to the very low surface slope and possibly a less permeable medium.

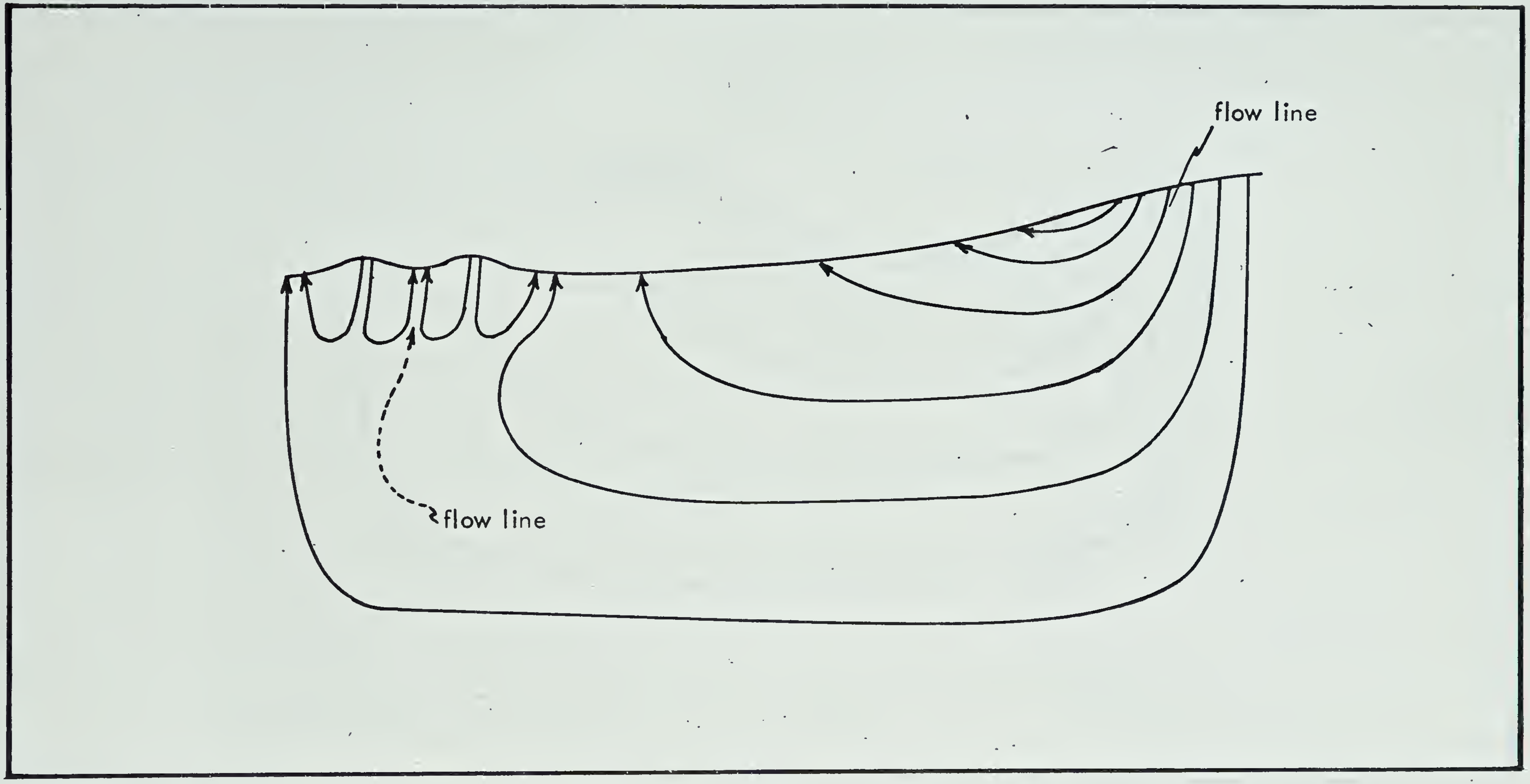


Figure 26. Diagrammatic hydraulic cross section with flow distribution similar to that which prevails parallel to maximum topographic gradient in the center of setting III.

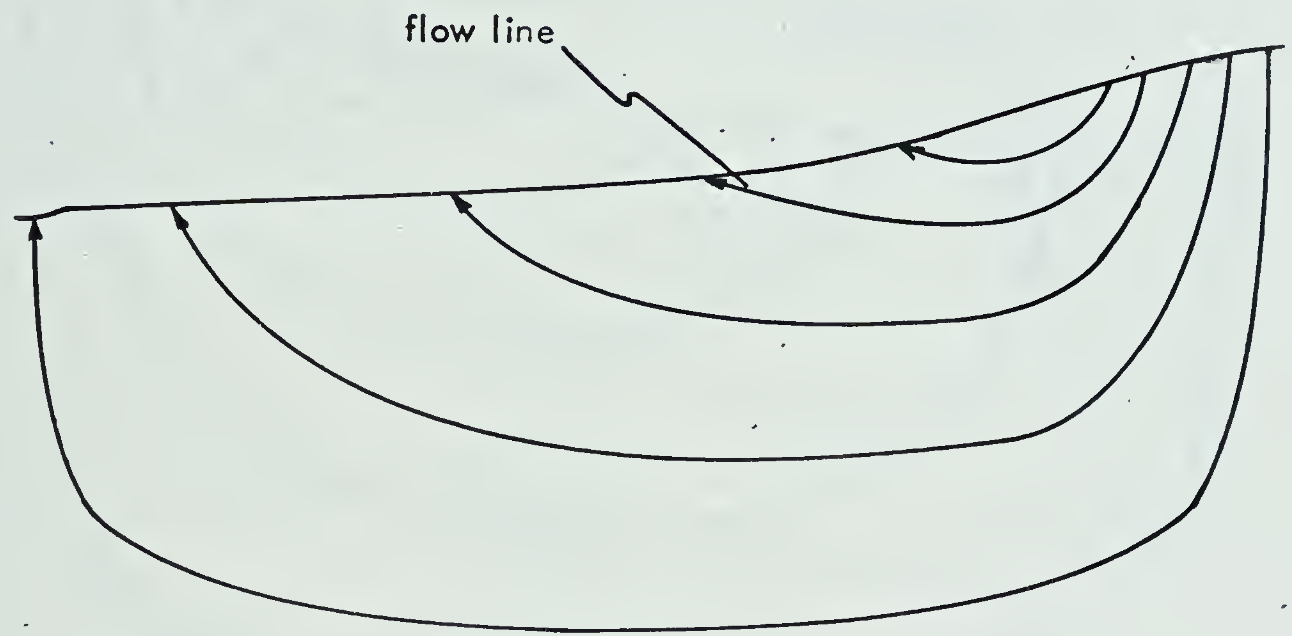


Figure 27. Diagrammatic hydraulic cross section with flow distribution similar to that which prevails parallel to maximum topographic gradient toward the northern edge of the area of setting III which was mapped.

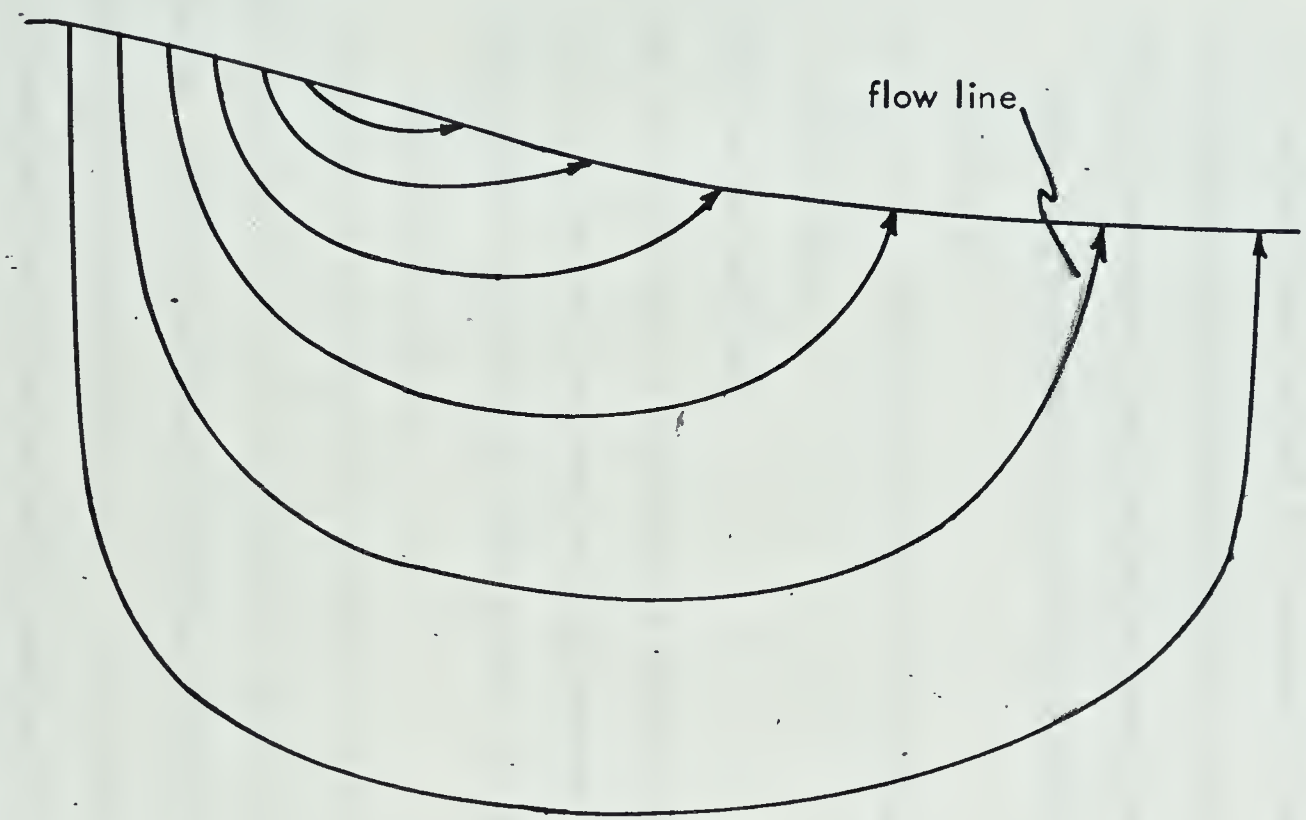


Figure 28. Diagrammatic hydraulic cross section with flow distribution similar to that which prevails parallel to maximum topographic gradient in setting IV.

4. Conclusions

4.1 Assessment of Mapping

In order to assess the value of the mapping of groundwater in the Red Deer area on the basis of naturally occurring surficial phenomena, it is desirable to list briefly the information which was obtained during the study:

1) A general knowledge of the groundwater quality, in the area as a whole.
2) The distribution of water quality on or near the land surface.
3) The distribution of any particular feature associated with the presence or absence of groundwater near the land surface, such as springs, "soap holes", etc.
4) The rates of discharge at features where groundwater outflows onto the land surface.
5) A water table map.
6) The distribution of recharge and discharge areas.
7) A qualitative interpretation of groundwater movement.
8) A better understanding of the general principles of the movement of groundwater by the observer.

Groundwater mapping can be carried out in an area providing it is possible to differentiate between features resulting from surface water and those resulting from groundwater. This is possible providing there is a shortage of surface water on or near the land surface during part of the year. If this condition is met, the collection of any of the information listed in the preceding paragraph is possible from the mapping of the groundwater from naturally occurring surficial phenomena. The mapping techniques will be the most useful in areas where there is no existing hydrogeologic information or where no man-made features exist for obtaining or controlling groundwater. However, this method of mapping can still be very useful in areas where there is some obtainable subsurface information. The combining of the information from the mapping of groundwater and other sources has two possibilities: first, similar

results can be checked, one against the other; second, one information source in part supplements the other. Consequently, there can be a fuller coverage of an area.

In any study to evaluate the groundwater resources of an area, there are three types of information required:

1) Distribution of areas with fluid potentials favorable for development of groundwater supplies;
2) Distribution of water quality;
3) Distribution of more permeable rocks.

From the mapping of groundwater on the basis of naturally occurring surficial features, it is possible to determine areas of favorable fluid potential; these will be areas of surfaceward-moving groundwater. The surface or near-surface distribution of groundwater quality can also be obtained from mapping. From this distribution it is possible to extrapolate, in a general manner, the water quality to at least depths of a few hundred meters. The distribution of more permeable material, however, is not directly obtainable, but in some areas it may be possible to suggest the type of permeability variation to be expected.

If it is supposed that no information could be obtained concerning the distribution of the permeability of the rocks, a knowledge of the distribution of favorable fluid potentials and the water quality will greatly reduce the possible area to be considered when proposing a test-drilling program to evaluate or utilize the groundwater resources of an area.

The application of this method of mapping is not restricted to studies involving groundwater exploration alone. Any field of science able to make use of any of the eight points listed at the beginning of this section would find this method of collecting information worthwhile.

In summary then, the mapping of groundwater on the basis of naturally occurring surficial phenomena is a definite asset if the features resulting from

groundwater can be differentiated from those of surface water origin. The method can be used for the following:

- to establish, or supplement existing hydrogeologic information
- to obtain any one or more of the eight results listed at the start of this section.

4.2 Outlines for Test-Drilling Program

The second purpose of this study is to provide the basis for a test-drilling program to secure an adequate water supply from groundwater sources.

a) East area

Figure 29a gives the proposed areas in which test drilling should be carried out in the east area. Locations 1a, 1b, 2a, and 2b should have shallow test holes, locations 3, 4, 5b, and 8 should have moderately deep test holes, while 5a, 6 and 7 could possibly have deep test holes. The chemical quality of the groundwater is believed to be best at locations 1 through 5, a little less desirable at locations 6 and 8, and least desirable at location 7. Hydraulically, 5a and 5b are probably best situated, but hydraulic indications at 8 and 4 are also good.

At locations 1a, 1b, 2a, and 2b, there is evidence of groundwater discharge. The discharge is thought to be the result of the local systems associated with dunes to the east of the locations. Any test holes in these areas should be in the order of 70 meters in depth, as poorer quality and less quantities of groundwater from the major highland will probably be encountered at greater depths. However, even with permeable rocks, the safe yields of wells at these locations would not be expected to be high, due to the relatively small recharge areas.

Locations 3 and 4 are located close to the recharge-discharge boundary. Test holes at these locations should not be excessively deep; 100 to 150 meters should indicate their worth. These areas should experience decreasing head with increased depth, due to the steep slope, but these test holes would serve to inter-

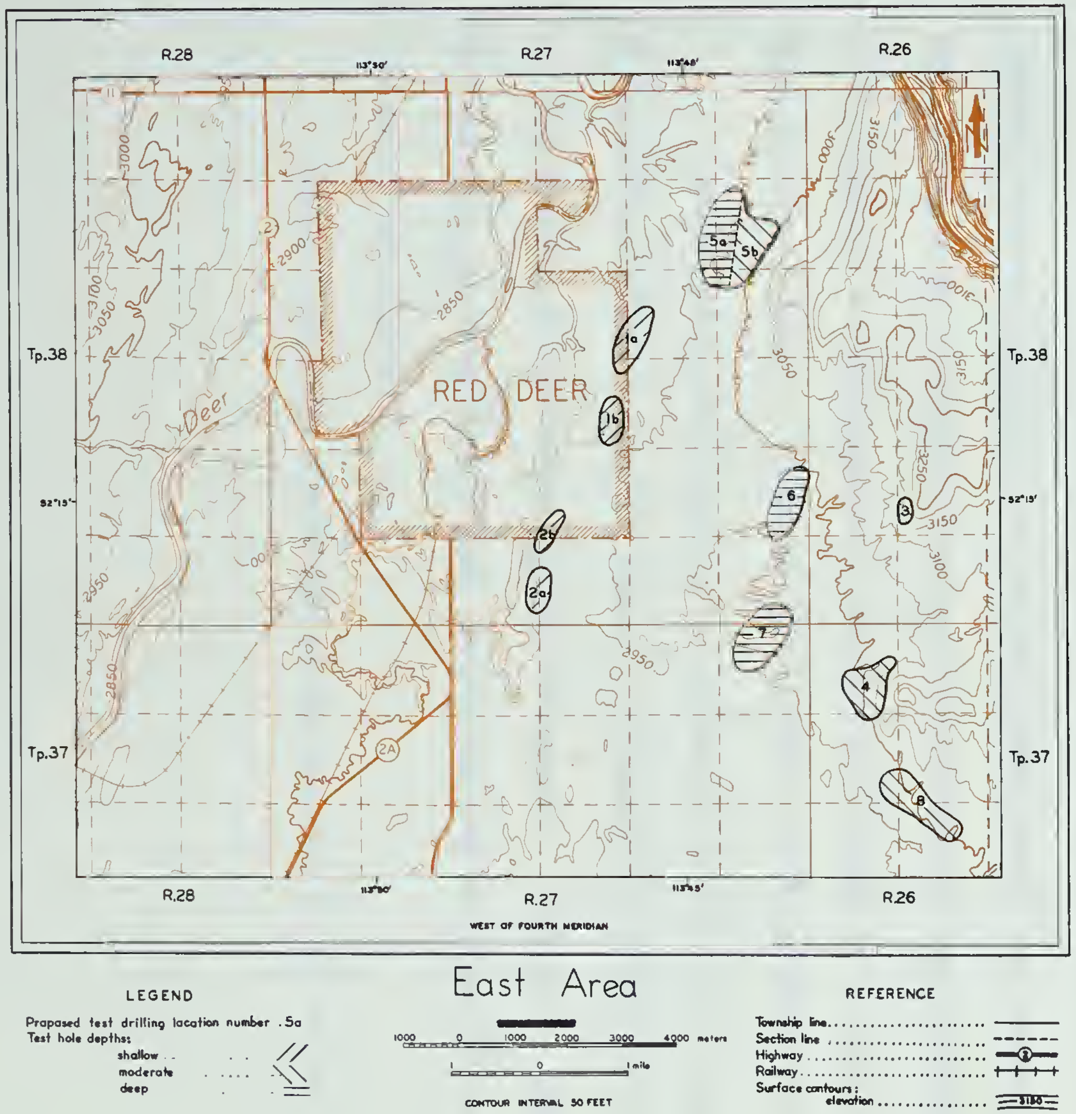


Figure 29a. East area: Map showing locations and areal extent of proposed sites for test drilling

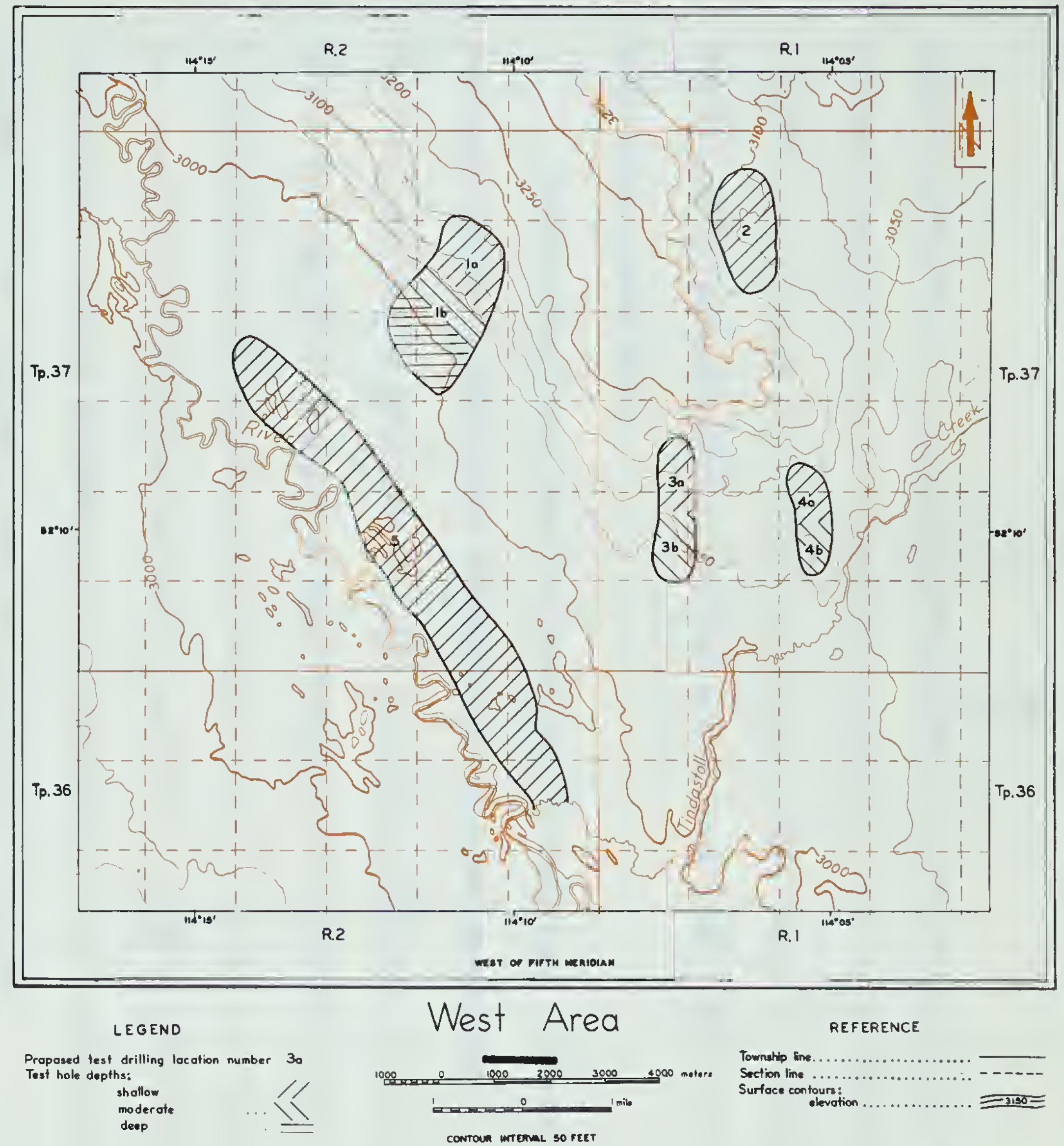


Figure 29b. West area: Map showing locations and areal extent of proposed sites for test drilling

cept a major part of the groundwater before it is lost naturally in the discharge area. At these locations, bedrock should be relatively close to the land surface; therefore, available drawdowns will not be very large. Also, areas of catchment for replenishment of the groundwater to the flow systems are small, making possible average long-range yields small.

At location 5a, a deep test hole may be required. However, a test hole in the order of 250 to 300 meters should be the greatest depth required. The great depth is intended to penetrate through the entire thickness of the drift and to penetrate the bedrock to a depth of approximately one hundred meters. If the bedrock is permeable enough to serve as an aquifer, and if the drift is thick, then there will be a combination of a high hydraulic head with a large available drawdown. If the bedrock is highly permeable, the development of an extensive cone of depression would allow relatively large average long-term yields.

Location 5b could be tested if 5a does not materialize. At 5b, a test hole should encounter less drift and the total depth should not exceed 100 to 150 meters. The permeability of possible aquifers at this location may be higher, due to fracturing of the bedrock on the preglacial valley wall thought to be present. However, long-term average yields would probably be similar to those of locations 3 and 4.

Locations 6 and 8 are similar in possibilities to 5a, except that the quality of the water will be somewhat poorer. At location 7 there is a similar possibility, but the quality of the water will be much poorer. However, there is the possibility of high average long-term yields, because of the location with respect to the configuration of the highland.

Table 3 contains a summary of the locations outlined for the east area.

Table 3. East area: Summary of proposed test-drilling locations

Location No.	Order of magnitude of test hole depth	Quality of groundwater	Hydraulic head	Average long-term yield*
1a	Few 10's of meters	Good	High	Low
1b	"	"	"	"
2a	"	"	"	"
2b	"	"	"	"
3	Up to 150 meters	"	Decreasing with depth	"
4	"	"	"	"
5a	Up to 300 meters	Very good	High	Moderate
5b	Up to 150 meters	"	"	Low
6	Up to 300 meters	Fair	"	Moderate-high
7	"	Poor	"	High
8	"	Fair	"	"

*Providing rocks of suitable permeability are encountered to act as aquifers.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

b) West area

Figure 29b gives the proposed areas in which test drilling should be carried out in the west area. The west area contains a rather unusual situation. There are two locations (1a and 2, Fig. 29b) in which large amounts of groundwater are outflowing in the form of springs. Therefore, before test drilling is carried out, the springs should be investigated as to whether it would be possible to adapt the discharge from the springs into a water supply.

If the development of a spring is too difficult, or yields are too low, then test drilling could be carried out in the vicinity of the springs. Locations 1a, 2, 3a, and 4a have a very good quality of groundwater, favorable groundwater potential, and indications of rocks having a high permeability. Test hole depths at these locations should not be excessive, probably not more than 50 to 100 meters. Long range yields at 1a and 2 should be moderate to high, while long range yields at 3a and 4a should be low to moderate.

Locations 1b, 3b, and 4b (Fig. 29b) are locations where test holes should be at least 100 to 150 meters deep. At these locations the drift thickness should show a considerable range, but should increase toward the thalweg. The groundwater will have a poorer quality than on the slope of the highland, but there probably will be a high hydraulic head and a relatively large available drawdown. Long-range yields should be higher in the region of the "b" locations than in the region of the corresponding "a" locations.

Location 5 (Fig. 29b) is in the area of sand dunes. The dunes have local flow systems associated with them. Test holes in area 5 should not be more than a few 10's of meters in depth; deeper test holes may encounter a poorer quality water present in the larger flow system passing under the local systems (Fig. 26). Long-range yields from wells in this area will inevitably be small because of the small recharge areas.

Table 4. West area: General evaluation of possible test hole locations

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Lower half of steep upland slope

- well depths 50 to 100 meters
- good quality water
- favorable fluid potential
- permeable rocks present
- low long-term yields (areas of moderate and high long-term yields are outlined)

Lowlands

- increase in required well depth as distance from highland increases
- decrease in water quality as distance from highland increases
- moderate to high long-term yields

Sand dune area

- well depths few 10's of meters
- good quality water
- low long-term yields

A summary of groundwater conditions for separate parts of the west area is given in table 4.

c) Limits of recommendations

The outlining of areas in which to test drill, from the results of mapping groundwater from naturally occurring suficial phenomena, at the present time leans quite heavily on theoretical considerations. In the future, as different sets of conditions are evaluated, a fund of experience will be available for a better evaluation of groundwater motion based on the mapping of naturally occurring surficial phenomena. Hence, areas in which to limit test drilling, depending upon the needs of the test, will be able to be outlined more specifically with a high degree of certainty.

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Appendix A

Schedule of observation points in the two areas near Red Deer and accompanying maps (maps in pocket)

Appendix A. East area observation points

Obs. Pt. No.	Location W. 4th Mer. 1/4	Sec.	Tp.	R.	Map elevation ft. above mean sea level	Main surficial feature; Relationship to local and/or regional topography
E-1	NE-19; SW-29;	NW-20; SE-30	37	26		
(a-1)					2988*	Flowing well
(a-4)					2987	Phreatophytes
(a-7)					2959*	Moist depression; closed depression
(a-9)					2974*	Gully; damp patches
(c-1)					2974*	Old soap hole
(c-8)					2981*	Flat-type soap hole
(c-10)					2982*	Mound-type soap hole
(c-10a)					2982	Mound-type soap hole
(c-10b)					2982	Mound-type soap hole
(c-10c					2983*	Flowing auger hole
(d-1)					2966*	Flowing shot hole
(d-3)					2963*	Seepage
(d-4)					2963*	Water level
(d-5)					2954*	Soap hole
(d-6)					2954*	Soap hole
(e-1)					2957*	Salt precipitates
(e-3)					2963	Core-type soap hole
(e-6)					2955*	Soap holes
(e-8)					2965*	"Young" mound-type soap hole
(f-1)					2988*	Auger hole
(g-4)					2988*	Spring
E-2	NE	19	37	26	2955	Salt precipitates
E-5	NE	19	37	26	2955	Unvegetated soil
E-6	NE	19	37	26	2945	Water standing; closed depression
E-7	NE	19	37	26	2947	Unvegetated soil
E-8	NE	19	37	26	2948	Vegetation zoned
E-9	NE	19	37	26	2943	Water standing; linear depression
E-10	NW	19	37	26	2947	Sparse vegetation
E-11	NW	19	37	26	2945	Water standing; closed depression
E-12	NW	19	37	26	2942	Phreatophytes; closed depression
E-13	NW	19	37	26	2941	Water flowing; linear depression -thalweg
E-14	NW	19	37	26	2944	Salt precipitates

*Elevations obtained by plane-table methods.

E-15	NW	20	37	26	2949	Water standing; road ditch
E-17	SE	20	37	26	2980	Water standing; closed depression
E-18	NE	20	37	26	3010	Damp depression; closed depression
E-19	NE	20	37	26	3020	Water standing; closed depression
E-20	NW	20	37	26	3020	Salt precipitates; flat land
E 22	NE	20	37	26	3023	Standing water; closed depression
E-23	NE	20	37	26	3025	Standing water; closed depression
E-24	NE	20	37	26	3030	Standing water; closed depression
E-25	NE	20	37	26	3040	Standing water; closed depression
E-26	NE	20	37	26	3020	Standing water; closed depression
Trav.	NE	29	37	26	3125-3150	
E-3	S1/4	32	37	26		
E-27	SE	32	37	26	3170	Standing water; closed depression
E-28	SE	29	37	26	3028	Damp depression; closed depression
E-29	SW	11	37	26	3006	Damp depression; closed depression
Trav. E-4	NW	29	37	26	3050-3100	Two linear depressions
E-31	SW	29	37	26	3010	Small depression; closed depression
E-32	NW	29	37	26	3055	Small depression; closed depression
E-33	NW	29	37	26	3075	Small depression; closed depression
E-34	NE	29	37	26	3107	Standing water; closed depression
E-35	NE	29	37	26	3088	Small depression; closed depression
E-36	NE	29	37	26	3075	Linear depression
E-37	NE	29	37	26	3073	Unvegetated soil; closed depression
E-38	SE	29	37	26	3070	Water standing; closed depression
E-39	SE	29	37	26	3063	Unvegetated soil; closed depression
E-39a	SE	29	37	26	3063	Unvegetated soil; closed depression
E-40	SE	29	37	26	3047	Water standing; closed depression
E-41	SE	29	37	26	3050	Vegetation greener
E-42	SE	29	37	26	3039	Water standing; closed depression
E-43	SE	29	37	26	3038	Water standing; closed depression
E-44	SE	29	37	26	3035	Phreatophytes; closed depression
E-45	NE	29	37	26	3104	Sparse vegetation; closed depression
E-46	SE	31	37	26	3150	Linear depression
E-47a	NE	31	37	26	3010	Hidden seepage; linear depression
E-47b	NE	31	37	26	3005	Hidden seepage; linear depression
E-47c	NE	31	37	26	3000	Hidden seepage; linear depression
E-47d	NE	31	37	26	3000	Water standing; closed depression
E-48	NE	31	37	26	3019	Small depression; closed depression
Trav.	NE	31	37	26	3000-3022	Linear depression
E-49	NW	32	37	26		
E-50	NW	32	37	26	3063	Small depression; closed depression
E-51	NW	32	37	26	3068	Small depression; closed depression
E-52	NW	32	37	26	3070	Small depression; closed depression
E-53	NW	32	37	26	3065	Small depression; closed depression
E-54	NW	32	37	26	3070	Linear depression
E-55	SW	31	37	26	2960	Water standing; closed depression
E-56	SW	31	37	26	2964	Shallow depression; closed depression
E-57	SW	31	37	26	2970	Brush patch
E-58	SW	31	37	26	2973	Adverse plant growing conditions; even slope
E-59	SW	31	37	26	2973	Water standing; closed depression
E-60	NW	31	37	26	2987	Water standing; closed depression

E-61	NE	31	37	26	2997	"Swamp"; linear depression
E-61a	NE	31	37	26	2998	"Swamp"; linear depression; seepage
E-62	NE	31	37	26	3022	Hard crusted soil; even slope
E-63	SE	31	37	26	2975	Adverse plant growing conditions; flat ground
E-64	SW	31	37	26	2965	Salt precipitates; slight depression
E-65	SW	30	37	26	2945	Willow patch
E-66	SW	30	37	26	2945	Salt precipitates
E-67	SW	30	37	26	2948	Brush patch
E-68	SW	30	37	26	2949	Damp depression; closed depression
E-69	SE	31	37	26	2949	Hard light-colored soil; man-made linear depression
E-70	SE	31	37	26	2958	Phreatophytes; linear depression
E-71	SE	31	37	26	2965	Brush patch
E-73	SE	31	37	26	2972	Phreatophytes; linear depression
E-75	NE	31	37	26	2995	Hard crusted soil; even slope
E-76	NE	31	37	26	2987	Hard crusted soil; even slope
E-77	NE	31	37	26	2980	Hard crusted soil; even slope
E-78	NE	31	37	26	2995	Hard crusted soil; even slope
E-79	SE	31	37	26	3005	Hard crusted soil; even slope
E-80	NE	30	37	26	2970	Hard crusted soil; even slope
E-81	NE	30	37	26	2961	Brush patch
E-82	NW	30	37	26	2948	Water standing; closed depression
E-83	SW	30	37	26	2949	Water standing; closed depression
E-84	SW	30	37	26	2949	Water standing; closed depression
E-85	SW	30	37	26	2948	Phreatophytes; closed depression
E-86	SW	30	37	26	2946	Water standing; closed depression
E-87	NE	36	37	26	2945	Phreatophytes; closed depression
Trav. E-88	SE	25	37	27	2950	Salt precipitates; low-lying land
Trav. E-89	NE	24	37	27	2945	Very shallow depressions
E-90a	SW	24	37	27	2935	Salt precipitates; creek bank
E-90b	SW	24	37	27	2935	Water standing; creek bottom
E-91a	SW	24	37	27	2935	Salt precipitates; flat surface
E-91b	NW	24	37	27	2933	Shallow depression; closed depression
E-91c	NW	24	37	27	2933	Damp depression; closed depression
E-91d	NW	24	37	27	2940	Water standing; closed depression
E-91e	NW	24	37	27	2945	Water standing; closed depression
E-91f	SW	25	37	27	2948	Phreatophytes; uniform growth of rushes in slight depression
E-91g	SW	25	37	27	2945	Shallow depression; closed depression
E-91h	SW	25	37	27	2947	Shallow depression; closed depression
E-91i	SW	25	37	27	2946	Small depression; closed depression
E-92a	SE	25	37	27	2945	Salt precipitates; closed depression
E-92b	SE	25	37	27	2944	Salt precipitates; closed depression
E-92c	SE	25	37	27	2945	Salt precipitates; closed depression
E-92d	SE	25	37	27	2945	Standing water; closed depression
E-92e	SW	25	37	27	2945	Salt precipitates; closed depression
E-92f	SW	25	37	27	2945	Salt precipitates; closed depression
E-92g	SW	25	37	27	2945	Salt precipitates; closed depression
E-92h	NW	25	37	27	2945	Shallow depression; closed depression
E-93a	NE	36	37	27	2955	Salt precipitates; closed depression
E-93b	NE	36	37	27	2955	Salt precipitates; closed depression

E-93c	NE	36	37	27	2955	Salt precipitates; linear depression
E-93d	NE	36	37	27	2949	Salt precipitates; closed depression
E-93e	NE	36	37	27	2953	Damp depression; closed depression
E-93f	NE	36	37	27	2955	Water standing; closed depression
E-93g	NE	36	37	27	2955	Sparse vegetation; road ditch
E-94a	NW	36	37	27	2945	Hard lumpy soil; linear depression
E-95a	NW	36	37	27	2945	Phreatophytes; linear depression
E-95b	SE	36	37	27	2947	Vegetation absent; even ground
E-95c	NE	36	37	27	2950	Water standing; closed depression
E-95d	NW	36	37	27	2947	Shallow depression; closed depression
E-95e	NW	36	37	27	2948	Phreatophytes; closed depression
E-95f	NW	25	37	27	2945	Water standing; closed depression
Trav. E-95	NE	36	37	27	2955	Linear depression
Trav. E-96	NW	8	38	26	3125-75	Linear depression
E-97a	SW	8	38	26	3140	Hummocky ground; side hill; hidden seepage
E-98a	NW	5	38	26	3080	A gully; salt precipitates
E-99a	SE	5	38	26	3050	Water standing; linear depression
E-99b	SW	8	38	26	3252	Water standing; closed depression
E-99c	NW	5	38	26	3095	Small depression; closed depression
E-99d	SW	5	38	26	3025	Salt precipitates; linear depression
Trav. E-100	SE	5	38	26	3080	Linear depression
E-101	NE	5	38	26	3110	Gullies
Trav. E-102	N1/2	8	38	26	3200	
E-102a	NE	8	38	26	3150	Side hill
E-103a	NW	7	38	26	3027	Salt precipitates; linear depression
E-103b	NW	7	38	26	3015	Vegetation absent; closed depression
E-103c	NE	7	38	26	3105	Shallow depression; closed depression
E-104a	SE	7	38	26	3025	Spring; at the base of crescent shaped steep local slope on even regional slope
E-104b	SE	7	38	26	3105	Sandy till
E-104c	SE	7	38	26	3120	Salt precipitates; even slope
E-105	NE	30	37	26	3040	Seepage; base of steep hill
E-106a	SE	6	38	26	3002	Water standing; closed depression
E-106b	SW	6	38	26	2973	Brush patch; closed depression
E-106c	SW	6	38	26	2974	Water standing; closed depression
E-106d	SW	6	38	26	3003	Brush patch; no noticeable depression
E-106e	SW	6	38	26	2985	Salt precipitates; closed depression
E-106f	SW	6	38	26	2968	Water standing; closed depression
E-106g	NW	6	38	26	2995	Water standing; closed depression
Trav.	NW	7	38	26	3000-3050	Linear depression
E-107	SW	18	38	26		
E-108a	NW	12	38	27	2973	Small depression; closed depression
E-108c	NW	12	38	27	2975	Salt precipitates; closed depression
E-108d	NW	12	38	27	2970	Salt precipitates; closed depression
E-108e	SW	12	38	27	2955	Shallow depression; closed depression
E-108f	NW	1	38	27	2945	Phreatophytes; closed depression
E-109	NW	12	38	27	2975	Shallow depression; closed depression
E-110a	NE	12	38	27	2990	Salt precipitates; linear depression
E-110b	NE	12	38	27	2970	Phreatophytes; linear depression

Trav. E-111	SE	12	38	27	2975	Willow patch
E-112a	NE	1	38	27	2945	Large depression; closed depression
E-112b	NE	1	38	27	2947	Hard crusted soil; very slight closed depression
E-112c	NW	1	38	27	2947	Hard crusted soil; very slight closed depression
E-112d	SW	1	38	27	2949	Salt precipitates; very slight closed depression
E-112e	SE	1	38	27	2960	Water standing; closed depression
E-112f	SW	1	38	27	2948	Damp depression; closed depression
E-112g	SE	1	38	27	2948	Water standing; closed depression
E-112h	NW	1	38	27	2965	Damp depression; closed depression
E-112i	SE	1	38	27	2960	Salt precipitates; even ground
E-112j	SE	1	38	27	2955	Phreatophytes; closed depression
E-112k	SW	1	38	27	2945	Salt precipitates; closed depression
E-113a	SW	1	38	27	2942	Standing water; closed depression
E-113b	SE	2	38	27	2947	Standing water; closed depression
E-113c	SE	2	38	27	2948	Phreatophytes; closed depression
E-113d	SE	2	38	27	2949	Phreatophytes; closed depression
E-113e	SE	2	38	27	2949	Damp depression; closed depression
E-114a	SE	17	38	26	3310	Water standing; closed depression
E-114b	SW	17	38	26	3270	Damp depression; closed depression
E-114c	SW	17	38	26	3265	Standing water; closed depression
E-114d	SE	17	38	26	3290	Standing water; closed depression
Trav. E-115	NW	17	38	26	3250	Regional high
Trav. E-116	SW	17	38	26	3175-3200	Linear depression
E-117a	SE	18	38	26	3135	Linear depression
E-117b	NE	18	38	26	3110	Vegetation variable; even slope
E-117c	NE	18	38	26	3150	Seepage; base of crescent steep slope on even regional slope
E-117d	NE	18	38	26	3160	Salt precipitates; even slope
E-118a	NE	18	38	26	3155	Seepage; base of crescent steep slope on even regional slope
E-119a	SE	13	38	27	3025	Adverse vegetal growing conditions
E-119b	SE	13	38	27	3030	Adverse vegetal growing conditions
E-119c	SE	13	38	27	3000	Phreatophytes; closed depression
E-119d	SE	13	38	27	2990	Damp depression; closed depression
E-120a	NE	13	38	27	3050	Salt precipitates; linear depression
E-120b	NE	13	38	27	3040	Standing water; very shallow closed depression
E-121a	NW	13	38	27	2980	Salt precipitates; closed depression
E-121b	SW	13	38	27	2975	Water standing; closed depression
E-122	SW	20	38	27	3275	Linear depression
Trav. E-123	S1/2	19	38	26	3100	
Trav. E-124	W1/2	19	38	26	2975-3225	
E-125a	NE	24	38	27	3075	Adverse vegetal growing conditions
E-125b	NE	24	38	27	3100	Well
E-126	SW	30	38	26	3070	Water standing; dugout

E-127a	NW	24	38	27	3010	Phreatophytes; slight flexure in even slope
E-127b	SW	24	28	27	3000	Salt precipitates; even ground
Trav. E-128	SW	30	38	26	3025-3150	
Trav. E-129	NW	30	38	26	3025-3150	Linear depression
Trav. E-130	SE	30	38	26	3175-3200	Regional high
Trav. E-131	E1/2	30	38	26	3150-3250	Regional high
E-132a	NW	30	38	26	3030	Spring; linear depression
E-132b	NW	30	38	26	3010	Salt precipitates; brush patch; slight depression
E-132c	NW	30	38	26	3015	Salt precipitates; gopher hole
E-132d	NW	31	38	26	2985	Water standing; dugout
E-132e	NW	31	38	26	2980	Salt precipitates; linear depression
E-132f	NW	31	38	26	2985	Salt precipitates; closed depression
Trav. E-133	E1/2	31	38	26	3050-3100	
Trav. E-134	NW	36	38	27	2925	
E-135	NW	36	38	27	2925	Salt precipitates; even ground
E-136a	SW	36	38	27	2925	Salt precipitates; linear depression
E-136b	SW	36	38	27	2925	Salt precipitates; linear depression
E-137a	NE	36	38	27	2965	Gully; linear depression
E-137b	SE	36	38	27	2975	Salt precipitates; closed depression
E-137c	SE	36	38	27	2980	Water standing; closed depression
E-137d	SE	36	38	27	2983	Phreatophytes; closed depression
E-137e	SE	36	38	27	2975	Salt precipitates; closed depression
E-137f	SE	36	38	27	2950	Small depression; linear depression
E-138a	NW	25	38	27	2928	Salt precipitates; even ground
E-138b	NW	25	38	27	2930	Adverse vegetal growing conditions; closed depression
E-139	SE	26	38	27	2950	Hard crusted soil
Trav. E-140	SW	25	38	27	2975-3000	Salt precipitates; slight linear depression
E-140a	SW	25	38	27	2965	Salt precipitates; slight linear depression
E-140b	SE	25	38	27	3015	Extremely hummocky ground; linear depression; hidden seepage
E-140c	SE	25	38	27	2985	Hard crusted soil; linear depression
E-140d	SE	25	38	27	3040	Gully; damp soil; even slope
E-140e	SE	36	38	27	2985	Salt precipitates; even ground
E-141a	SW	26	38	27	2900	Shallow damp depression; closed depression
E-141b	SW	26	38	27	2920	Phreatophytes; linear depression
E-141c	SE	26	38	27	2903	Phreatophytes; slight linear depression
E-141d	SE	26	38	27	2935	Gully
E-141e	SE	26	38	27	2930	Phreatophytes; slight depression
E-142	NW	26	38	27	2900	Earth dams
E-142e	NW	26	38	27	2898	Phreatophytes
E-143	NE	26	38	27	2945	Outcrop - glacial material
E-144a	SW	35	38	27	2903	Saltprecipitates; very slight depression

E-144b	SW	35	38	27	2965	Seepage; linear depression
E-144c	NE	34	38	27	2825	Damp soil patches; side hill
E-145	SW	35	38	27	2885	Damp depression
E-146	SE	34	38	27	2875	Outcrop glacial material
E-147a	SE	27	38	27	2890	Salt precipitates; closed depression
E-147b	NE	27	38	27	2885	Small depression; closed depression
E-147c	SE	27	38	27	2900	Shallow depression; closed depression
E-147d	NE	22	38	27	2903	Shallow depression; closed depression
E-147e	SE	27	38	27	2860	Seepage; south bank of linear depression
E-148	NE	23	38	27	2950	Well
E-149a	NW	23	38	27	2930	
E-149b	NW	23	38	27	2924	Small depression; closed depression
E-150	NW	23	38	27	2908	Well
E-151a	SW	23	38	27	2918	Salt precipitates; slight linear depression
E-151b	SW	23	38	27	2930	Water standing
E-151c	SW	23	38	27	2940	Broad shallow depression
E-152	SW	23	38	27	2925	Gravel pit
E-153a	NW	22	38	27	2905	Salt precipitates; even ground
E-153b	NE	22	38	27	2915	Small treed depression
E-153c	SE	22	38	27	2915	Salt precipitates; even ground
E-153d	SE	22	38	27	2914	Broad shallow depression; closed depression
E-153e	SE	22	38	27	2920	Broad shallow depression; closed depression
E-153f	SE	22	38	27	2918	Shallow depression; closed depression
E-154	NE	22	38	27	2915	Well
E-155a	NE	15	38	27	2922	Salt precipitates; closed depression
E-155b	SE	15	38	27	2910	Salt precipitates; linear depression
E-155c	SE	15	38	27	2898	Salt precipitates
E-155d	SE	15	38	27	2900	Hard crusted soil; even slope
E-156a	SW	14	38	27	2948	Water standing; closed depression
E-156b	SW	14	38	27	2946	Dugout
E-157a	SE	14	38	27	2960	Water standing; closed depression
E-157b	SE	14	38	27	2955	Salt precipitates; closed depression
E-157c	SE	14	38	27	2955	Salt precipitates; closed depression
E-158a	NE	11	38	27	2975	Phreatophytes; closed depression
E-158b	NE	11	38	27	2970	Damp soil patches; ditch edge
E-158c	NE	11	38	27	2970	Salt precipitates; closed depression
Trav. E-159	NE	11	38	27	2950-2975	Depressions, damp-standing water; closed depression
E-159k	NE	11	38	27	2960	Light grey tinge to soil
E-159l	NE	11	38	27	2960	Hard crusted soil; side hill
E-159q	SW	11	38	27	2955	Hard crusted soil
E-160a	NE	10	38	27	2945	Outcrop; glacial deposits; closed depression
E-160b	NW	10	38	27	2955	Damp depression; closed depression
E-160c	NW	10	38	27	2965	Small depression; closed depression
E-161a	SE	10	38	27	2945	Salt precipitates; closed depression
E-162a	SW	2	38	27	2955	Damp shallow depression; closed depression
E-162b	SW	2	38	27	2961	Small deep depression; closed depression

Trav. E-162	N1/2	2	38	27		Depressions, damp - standing water
E-162e	SW	11	38	27	2965	Hard crusted soil; slight depression on local topographic high
E-162h&i	NE	2	38	27	2950	Depressions; closed
E-162k	SW	2	38	27	2957	Small depression; closed depression
E-162l	SW	2	38	27	2954	Phreatophytes; closed depression
E-163a	SW	2	38	27	2955	Broad shallow depression; closed depression
E-163b	SW	2	38	27	2956	Damp depression; closed depression
E-163c	SW	2	38	27	2954	Damp depression; closed depression
E-163d	SE	2	38	27	2949	Damp depression; closed depression
E-163e	SE	2	38	27	2948	Damp depression; closed depression
E-163f	SE	2	38	27	2945	Broad shallow depression; closed depression
E-163g	SE	2	38	27	2948	Damp depression; closed depression
E-163h	SW	2	38	27	2960	Damp depression; closed depression
E-164a	NW	3	38	27	2910	Salt precipitates; closed depression
E-164b	NW	10	38	27	2903	Salt precipitates; closed depression
E-164c	SW	3	38	27	2910	Hard crusted soil; closed depression
E-164 d,e,f	SW	3	38	27	2912-2917	Damp soil; closed depression
E-164g	SW	3	38	27	2910	Light grey tinge to soil; closed depression
E-164h	SW	3	38	27	2910	Average soil moisture; closed depression
E-164i	NW	3	38	27	2918	Salt precipitates; closed depression
E-164j	NW	3	38	27	2918	Average soil moisture; closed depression
E-164k	SW	10	38	27	2920	Light grey tinge to soil; closed depression
E-164l	SW	10	38	27	2910	Salt precipitates; closed depression
E-164m, n,o,p, q & r	W1/2	10	38	27	2910	Semi-permanent sloughs
E-165a	SE	26	37	27	2945	Very shallow depression
E-165b	SE	26	37	27	2945	Shallow depression
E-165c	SE	26	37	26	2950	Damp soil; local topography low
E-165 d & e	NE	26	37	27	2945	Damp soil; local topography low
E-165f, g & h	NE	26	37	27	2940	Salt precipitates; local topography low
E-165i	NE	26	37	27	2935	Salt precipitates; local topography low
E-165j, k & l	NE	26	37	27	2930	Light grey tinge, lumpy soil
E-165m	NE	26	37	27	2935	Large shallow depression; closed depression
E-165n	SE	26	37	27	2935	Salt precipitates
E-166	SW	35	37	27	2935	Broad shallow depression; closed depression

E-167a	SE	26	37	27	2930	Salt precipitates; slight linear depression
E-167b	SE	26	37	27	2928	Salt precipitates
E-167c	SW	27	37	27	2930	Vegetation type; closed depression
Trav. E-168	NW	26	37	27	2930	
E-169a	SE	26	37	27	2930	Water standing; road ditch
E-169b	SE	26	37	27	2930	Water standing; road ditch
E-169c	SE	26	37	27	2930	Salt precipitates; soil profile
E-169d	NE	23	37	27	2930	Sparse vegetation; even ground
E-170a	SW	26	37	27	2930	Sparse vegetation; even ground
E-170b	SE	26	37	27	2930	Sparse vegetation; even ground
E-170c						Summary of discharge features in local area
E-171	NE	35	37	27	2948	Water standing; closed depression
E-172a	SE	35	37	27	2940	Damp soil; closed depression
Trav. E-173	NW	34	37	27	2920	Water standing; closed depression
E-174	SW	27	37	27	2945	Salt precipitates; closed depression
E 175	SW	27	37	27	2945	Phreatophytes; closed depression
E-176	SW	27	37	27	2945	Salt precipitates; closed depression
E-177	SW	27	37	27	2945	Outcrop; sand
E-178	SE	27	37	27	2940	Sparse vegetation; small gully
E-179	SE	27	37	27	2940	Hard lumpy soil; closed depression
E-180	NE	27	37	27	2920	Water standing; creek bottom
E-181a	NE	35	37	27	2948	Salt precipitates; large closed depression
E-181b	SE	35	37	27	2940	Damp soil; closed depression
E-181c	NW	35	37	27	2950	Damp soil; closed depression
E-181d	NW	35	37	27	2955	Damp soil; closed depression
E-182a	NE	27	37	27	2945	Water standing; closed depression
E-182b	SE	27	37	27	2940	Adverse growing conditions
E-182c	SW	27	37	27	2945	Hard crusted soil; closed depression
E-182d	NW	27	37	27	2945	Damp soil; closed depression
E-183a	NW	33	37	27	2900	Water standing; low between sand dunes
E-183b	NE	33	37	27	2890	Adverse growing condition; broad shallow closed depression
E-183c	NE	28	37	27	2930	Extremely hummocky ground; closed depression
E-183d	NE	28	37	27	2920	Water standing; closed depression
E-183e	SE	28	37	27	2945	Damp soil
E-184	SE	28	37	27	2945	Damp soil;
E-185a	SW	28	37	27	2920	Water standing; road ditch
E-185b	SW	28	37	27	2920	Adverse vegetation growing conditions; even ground
E-185c	SW	28	37	27	2920	Hard crusted soil; even ground
E-186a	SW	28	37	27	2920	Salt precipitates; road ditch
E-186b	SW	28	37	27	2920	Salt precipitates; closed depression
E-186b	NW	28	37	27	2920	Salt precipitates; closed depression
E-187a	NW	28	37	27	2925	Phreatophytes; closed depression
E-187b	NW	28	37	27	2925	Phreatophytes; closed depression
E-188	NW	28	37	27	2925	Outcrop; sand dune
E-188Aa	NW	33	37	27	2920	Salt precipitates
E-189a	NW	28	37	27	2920	Soft ground; closed depression

E-189b	NW	28	37	27	2925	Hard crusted soil; even ground
E-189c	SW	28	37	27	2920	Damp soil; closed depression
E-190a	NE	4	38	27	2890	Hard crusted soil
E-190b	SE	4	38	27	2890	Phreatophytes; broad shallow closed depression
E-191a	SE	4	38	27	2895	Damp soil; gully wall
E-191b	SE	4	38	27	2895	Outcrop; Pleistocene deposits
Trav. E-192	W1/2	4	38	27	2895	Salt precipitates
E-193	SE	5	38	27	2895	Spongy bottom slough; area of sand dunes
Trav. E-195	N1/2	5	38	27		
E-196a	SW	7	38	27	2895	Depression; closed depression
E-196b	SW	6	38	27	2895	Phreatophytes; large shallow closed depression
E-196c	SW	6	38	27	2895	Auger hole in vicinity of phreatophytes
E-197a	SE	12	38	28	2902	Average soil moisture; closed depression
E-197b	SE	12	38	28	2905	Average soil moisture; closed depression
E-198a	NW	1	38	28	2910	Damp soil; closed depression
E-198b	NW	1	38	28	2915	Damp soil;
E-199a	SE	12	38	28	2890	Damp soil
E-199b	SE	12	38	28	2895	Damp soil
E-199c	SE	12	38	28	2910	Damp soil
Trav. E-200	SE	1	38	28		Phreatophytes
E-201	SW	1	38	28		Farmer's report
E-202	SW	1	38	28	2850	Spring; at base of river bank
Trav. E-203	SE	26	37	28	2925	Salt precipitates; broad low area
E-204	SE	26	37	28	2928	Water standing
E-205a	SE	35	37	28	2940	Damp soil; closed depression
E-205b	NE	35	37	28	2935	Damp soil; closed depression
E-205c	NE	26	37	28	2935	Damp soil; closed depression
E-206	NE	36	37	28	2915	Salt precipitates
E-207	NE	36	37	28	2915	Damp soil; closed depressions
E-208	NW	9	38	27	2850	Seepage; linear depression
E-209	NE	4	38	27	2875	Seepage; linear depression
E-210	SW	17	38	27	2836	Spring; linear depression
E-211	SW	18	38	27	2836	Spring; linear depression

Appendix A. West area observation points

Obs. Pt. No.	Location W. 5th Mer. 1/4	Sec.	Tp.	R.	Map elevation ft. above mean sea level	Main surficial feature; Relationship to local and/or regional topography
W-1	SW	25	37	2	3125	Seepage area; head of linear depression
W-2	NE	26	37	2	3125	Salt precipitates in a gully
W-3	NE	26	37	2	3140	Spring; bank of linear depression
W-4	NE	26	37	2	3130	Salt precipitates
W-5	NE	26	37	2	3145	Pronounced depression
W-6	NE	26	37	2	3135	Seepage area
W-7	NW	35	37	2	3215	Slight depression
W-8	NE	35	37	2	3235	Very shallow depression
W-9	NE	35	37	2	3245	Slight broad depression
W-10a	SW	26	37	2	3045	Auger hole and water level
W-10b	SW	26	37	2	3025	Salt precipitates
W-11c	NW	26	37	2	3110	Auger hole and water level; even slope
W-12	SE	34	37	2	2110	Spring; head of linear depression
W-13	SE	34	37	2	3135	Shallow depression
W-14	NW	26	37	2	3120	Seepage area; side hill
W-15	NE	36	37	2	3225	Very slight depression
W-16	SW	36	37	2	3255	Pronounced depression; local relief 2 or 3 meters
W-17	SW	36	37	2	3250	Small shallow depression
W-18	SW	25	37	2	3190	Sandstone outcrop
W-19	SW	30	37	1	3255	Auger hole
W-20	SW	30	37	1	3255	Pronounced depression
W-21	NW	30	37	1	3255	Small depression
W-22	NE	25	37	2	3255	Broad shallow depression
W-23	NE	25	37	2	3255	Large depression
W-24	NE	25	37	2	3255	Shallow depression
W-25	NE	25	37	2	3255	Shallow depression
W-26	NE	25	36	2	3255	Shallow depression
W-27	SE	36	37	2	3255	Shallow depression; local relief 6-10 meters
W-28	NE	25	37	2	3255	Very shallow depression
W-30	NW	36	37	2	3255	Large shallow and broad depression
W-31	NW	24	37	2	3175	Seepage; gully in a linear depression
W-32	SW	24	37	2	3150	Spring; gully in a linear depression
W-33	SE	24	37	2	3160	Spring; base of sudden change in slope
W-34	NE	14	37	2	~3025	Less fertile soils; diminished declivity
W-35	SE	13	37	2	3045	Water standing; gully
W-36	NE	13	37	2		Seepage; gully
Trav. W-37	W1/2	19	37	1	3250	Depressions; subdued hummocky disintegration moraine
W-38	SW	18	37	1	3115	Dug well; water level
W-39	SE	18	37	1	3150	Damp soil; side hill
W-40	NE	18	37	1	3150	Well; water level

W-41	SW	18	37	1	3170	Hydrophytic vegetation
W-42	SW	18	37	1	3150	Damp soil; side hill
Trav. W-43	E1/2	19	37	1	3250	Depression; subdued hummocky disintegration moraine
W-44a	NW	17	37	1	3150	Dried up spring; base of local steep slope
W-44b	NW	17	37	1	3150	Spring; gully in linear depression
W-44c	NW	17	37	1	3145	Short trees
Trav. W-46	SW	17	37	1	3100	Phreatophytes and salt precipitates; shallow linear depression
W-47	SE	17	37	1	3170	Short trees; slight slope; hummocky ground; hidden seepage
W-48	SE	17	37	1	3130	Damp peaty soil; slight slope
W-49	SE	17	37	1	3130	Seepage; damp peaty soil; slight slope
W-50	SW	16	37	1	3090	Water standing; extremely hummocky; hidden seepage
W-51	SE	20	37	1	3255	Broad shallow depression; local slope .025
Trav. W-52	N1/2	20	37	1	3125-3250	Numerous linear depressions; steep slopes
W-52a	NW	20	37	1	3190	Gully
W-52b	NE	20	37	1	3175	Sparse vegetation
W-53	SW	16	37	1	3095	Phreatophytes; side hill
W-54	SE	16	37	1	3045	Phreatophytes;
W-55	NE	16	37	1	3075	Auger hole; water level
W-56	NE	21	37	1	3065	Hard crusted soil and phreatophytes
W-57	NE	21	37	1	3135	Phreatophytes; slight slope
W-58	NE	21	37	1	3110	Less fertile soil
W-59	NE	21	37	1	3080	Less fertile soil
W-60	SW	9	37	1	3055	Hard crusted soil; auger hole
W-61	NW	9	37	1	3075	Hard crusted soil
W-62	SW	4	37	1	3010	Salt precipitates
Trav. W-63	NE	9	37	1	3050	Phreatophytes
W-64	NE	9	37	1	3080	Hard crusted soil; side hill
W-65	NW	8	37	1	3095	Phreatophytes; linear depression
W-66a	SW	8	37	1	3055	Salt precipitates
W-66b	SW	8	37	1	3055	Salt precipitates
W-66c	SW	8	37	1	3050	Hard crusted soil
W-67	SE	7	37	1	3040	Hard crusted soil; auger hole
W-67a	SE	7	37	1	3045	Hard crusted soil; auger hole
W-68	SE	8	37	1	3075	Phreatophytes
W-69a	SE	8	37	1	3055	Salt precicipitates
W-69b	NE	5	37	1	3025	Salt precipitates
Trav.	NE	5	37	1	3000-3050	Patchy vegetation
W-70	NE	6	37	1		
	W1/2	6	37	1		
W-71	NW	12	32	2	3020	Salt precipitates
Trav. W-72	N1/2	1	32	2	2940	Hard crusted soil; north end of sand dunes divide area
W-72a	NW	1	32	2	2940	Phreatophytes; low region
W-72b	NW	1	32	2	2940	Salt precipitates; slight depression
W-73	NW	32	37	1	3005	Phreatophytes; auger hole

Trav. W-74	NW	1	37	2	3010	Patchy vegetation
W-74a	NW	1	37	2	3010	Salt precipitates
W-75a	SW	29	36	1	3000	Spring reported - east bank Tindastoll Creek
W-75b	NW	29	36	1	3000	Spring reported - east bank Tindastoll Creek
W-76	SW	29	36	1	2995	Damp soil - east bank Tindastoll Creek
W-77	NE	32	36	1	3015	Hard crusted soil
W-78a	SW	30	36	1	2990	Damp soil reported
W-78b	SW	25	36	1	2950	Seepage - reported
W-78c	SW	25	36	1	2950	Seepage - reported
W-78d	SE	24	36	2	2930	Spring reported
W-79	NE	30	36	1	3010	Hard crusted soil; very slight depression
W-80	NE	35	36	2	2985	Salt precipitates; pronounced topographic low between sand dunes
W-81a	SW	36	36	2	2970	Hard crusted soil; interdune area
W-81b	NW	36	36	2	2980	Phreatophytes; sparse hummocks; interdune area
W-82	SE	35	36	2	2985	Crusted sandy soil; interdune area
Trav. W-83	SE	2	36	2	2975	Light grey soil; lower areas of traverse
W-83a	SE	2	36	2	2975	Small depression
W-84	SW	11	36	2	3000	Sand dune; auger hole
W-85	NW	11	36	2	2990	Hard crusted soil; even slope
W-86	NE	10	36	2	2990	Salt precipitates
W-87	NE	10	36	2	2990	Flowing shot hole - reported
W-88	NW	11	36	2	2990	Large depression; interdune area
W-89	SW	11	36	2	2985	Salt precipitates
W-90	SE	14	36	2	3025	Water level
W-91	SE	23	36	2	3025	Hard crusted soil
W-92	NW	23	36	2	3035	Salt precipitates
W-93	SE	14	36	2	3010	Salt precipitates
Trav. W-94	SW	14	36	2	2995	Patchy vegetation
W-95	E1/2	15	36	2	2990	Salt precipitates
W-96	SE	15	36	2	2995	Damp soil in patches
W-97	SE	21	36	2	2990	Large shallow depression
W-97a	SW	22	32	2	2990	Salt precipitates
W-98	NW	22	36	2	2990	Slight linear depression
W-99	NE	22	36	2	2990	Saturated peat
W-100	SW	15	36	2	2970	Seepage area; meander of Medicine River
W-101	NW	23	36	2	3000	Hard crusted soil
W-102a	NW	23	36	2	3000	Patchy vegetation; even slope
W-102b	NE	23	36	2	3010	Seepage; gully on even slope
Trav.	SW	23	36	2	2995	Phreatophytes on a peat soil
W-103a	NW	14	36	2		
Trav. W-103b	NW	14	36	2	3010	Hard crusted soil
W-104	NE	22	36	2	2990	Standing water
W-105	SE	34	36	2	3100	Damp soil; even slope
W-106	NE	34	36	2	3095	Uncultivated region; even slope
Trav.	SE	33	36	2	3000	Hard crusted soil on N1/2 of trav.
W-107	NE	28	36	2		

W-107a	SE	33	36	2	2995	Water flowing
W-108a, b, c, & d	E1/2	27	36	2	3000	Hard crusted soil; even slope
W-108e	NE	27	36	2	3045	Patchy vegetation
W-108f	SW	34	36	2	3040	Intermittent spring - reported
W-109a	NE	27	36	2	3105	Phreatophytes; slight linear depression
W-109b	NE	27	36	2	3105	Small brush patch
W 109c	NW	26	36	2	3125	Small seepage
W-110a	NE	34	37	2	3140	Seepage; north bank of incised linear depression
W-110b	NW	34	37	2	3050	Phreatophytes; even slope
W-111	SE	3	38	2	3145	Water flowing from brush patch; slight depression
W-112	NE	34	37	2	3145	Flowing shot hole
W-113	NE	34	37	2	3145	Spring
W 114	SW	33	37	2	2990	Patchy vegetation
W-115	SW	33	37	2	2990	Dug well, water level
W-116	SW	33	37	2	2990	Patchy vegetation
W-117	NW	32	37	2	3010	Damp soil; auger hole
Trav. W-118	S1/2	32	37	2	2990	Sparse vegetation
W-118a	SE	32	32	2	2990	A few scattered trees; hole dug
W-118b	SW	32	37	2	2990	Shallow broad depression
W-119	SE	10	37	2	2970	Seepage; east bank of Medicine River
W-120	NE	9	37	2	2975	Seepage; east bank of Medicine River
W-121	NE	9	37	2	2975	Spring; east bank of Medicine River
W-122	SW	32	37	2	2986	Seepage; east bank of Medicine River
W-123	SW	32	37	2	2990	Damp shallow depression
W-124a	SE	29	37	2	2990	Water standing; shallow depression
W-124b	NW	29	37	2	2990	Water standing; shallow depression
W 124c	NW	29	37	2	2990	Water standing; shallow depression
W-125	NW	29	37	2	2980	Water standing; shallow depression
W-126	SW	29	37	2	2975	Damp ground; east bank of Medicine River
Trav. W-127	N1/2	31	37	1	3175-3325	Subdued hummocky moraine
W-127a	NW	31	37	1	3225	Gully
Trav. W-128	NW	30	37	1	3200	Several depressions
W-129	NE	30	37	1	3195	Spring in the past - reported
W-129a	NW	29	37	1	3175	Damp soil reported
W-130	NW	29	37	1	3135	Water standing; gully
W-131	SW	29	37	1	3140	Water standing;
W-131a	NE	29	37	1	3110	Damp peaty soil; even slope
W-132	SW	29	37	1	3145-3225	Damp patches of soil
W-133	SE	29	37	1	3115	Salt precipitates; gully
W-133a	SE	29	37	1	3120	Spring in the past
W-134	SE	32	37	1	3105	Salt precipitates
W-135	SE	32	37	1	3115	Phreatophytes; very slight depression
W-136	SE	32	37	1	3115	Saturated soil on a slope 0.02
W-137	SE	32	37	1	3120	Standing water; slight slope
W-138	NE	32	37	1	3090	Damp soil
W-139	NE	32	37	1	3080	Damp soil

W-140	NE	32	37	1	3070-3125	Spring; even slope
W-141	NW	28	37	1	3070	Salt precipitates
W-142a	NW	28	37	1	3070	Hard crusted soil
W-142b	SE	33	37	1	3060	Damp soil
W-142c	NW	33	37	1	3070	Phreatophytes
W-142d	SW	33	37	1	3070	Flowing shot hole - reported
W-143	NE	33	37	1	3075	Hard crusted soil
W-144	NW	34	37	1	3075	Salt precipitates
W-145	NW	34	37	1	3075	Salt precipitates
W-146	SE	28	37	1	3060	Salt precipitates
W-147	SE	28	37	1	3060	Salt precipitates; broad shallow depression
W-148	SE	28	37	1	3065	Hard crusted soil
Trav. W-149	SE	28	37	1	3065-3090	Salt precipitates
W-150	SE	4	38	1	3085	Spring
W-150a	SE	4	38	1	3095	Water well
W-151	SE	5	38	1	3105	Spring; head of linear depression
W-152	SE	29	37	1	3150	Spring
W-153	SW	21	37	2	2980	Peat soil; small depression
W-154	NE	9	37	1	3060	Hard crusted soil
W-155	SW	15	37	1	3075	Salt precipitates
W-156	SW	15	37	1	3075	Salt precipitates

Appendix B

List of chemical analyses of water samples

Appendix B. East area: list of chemical analysis of water sampled

Obs. Pt. No.	Date sampled	pH	T.D.S. (ppm)	Ca plus Mg (epm)	Na+K (epm)	Na+K %of total cations	HCO_3 $+CO_3$ (epm)	Cl (epm)	SO_4 (epm)	HCO_3 $+CO_3$ %of total anions	SO_4 %of total anions	Type (see Fig.14)	Remarks
E-1(a-1)	6/16/66	8.0	1200	3	15.8	84	11	0.4	7.4	59	39	III	Flowing well†
E-1(a-7)	6/15/66	8.0	800	4	6.1	58	7	0.4	3.1	67	30	-	Surface water†
E-1(e-6)	6/20/66	8.0	1300	4	14.3	78	17	0.4	0.9	93	5	III	Seepage(soap hole)†
E-1(c-10a)	7/27/66	8.0	900	2	17.8	90	12	1.2	6.6	61	33	III	Spring (soap hole)†
E-1(c-10c)	7/27/66	8.0	1100	1	19.9	96	14	0.8	6.1	67	29	III	Auger hole - flowing†
E-1(d-1)	7/28/66	8.5	800	2	14.8	88	11	0.8	5.0	62	28	III	Flowing shot hole†
E-1(d-1)	1/1/67	8.5	800	2	15.7	89	12	0.8	4.9	68	28	III	Flowing shot hole†
E-1(d-3)	6/14/66	8.5	800	2	12.7	86	10	0.4	4.3	68	29	III	Seepage†
E-1(f-1)	7/17/66	8.0	600	8	5.4	40	10	1.2	2.2	75	16	II	Hidden seepage†
E-1(f-1)	7/17/66	8.5	600	8	4.7	37	9	1.2	2.5	71	20	II	Hidden seepage†
E-1(f-1)	8/10/66	8.6	490	4.6	3.5	43	6.2	0.3	1.7	76	21	II	Hidden seepage*
E-1(f-1)	6/16/66	8.0	1300	14	2.2	14	12	0.4	3.8	74	24	-	Surface water†
E-14	6/15/66	8.6	800	8	7	47	8	0.4	6.6	53	44	-	Surface water†
E-15	6/15/66	8.0	1400	8	9.4	54	12	0.4	5.0	69	28	-	Surface water†
E-17	6/16/66	8.0	200	2	0.7	26	2	0.4	0.3	74	11	-	Surface water†
E-23	6/16/66	8.0	300	4	1.9	32	3	2.4	0.5	51	8	-	Surface water†
E-27	6/16/66	8.0	200	2	0.9	31	2	0.4	0.5	69	20	-	Surface water†
E-34	6/17/66	8.0	100	1	0.7	41	1	0.4	0.3	59	18	-	Surface water†
E-38	6/17/66	8.0	300	4	-0.3	0	3	0.4	0.3	81	8	-	Surface water†
E-40	6/17/66	8.6	100	1	1.1	52	1	0.8	0.3	52	14	-	Surface water†
E-42	6/17/66	8.7	400	4	1.1	22	4	0.8	0.3	78	6	-	Surface water†
E-47a	7/17/66	8.0	600	5	6.7	57	9	0.8	1.9	77	16	II	Hidden seepage†
E-55	6/18/66	8.0	200	2	1	33	2	0.8	0.2	67	3	-	Surface water†
E-61a	7/6/66	8.7	800	1	15.2	94	12	0.4	3.8	74	24	III	Seepage (swamp)†

†Analysis by field methods
*Analysis by Provincial Analyst.

E-82	6/20/66	8.0	300	2	0.9	31	2	0.4	0.5	69	20	-	Surface water†
E-84	6/20/66	8.6	1100	12	3.4	22	11	2.0	2.4	72	16	-	Surface water†
E-97a	7/17/66	8.0	800	6	10.4	64	11	0.8	4.6	67	28	II	Hidden seepage†
E-97a	8/10/66	8.8	708	3.6	7.9	65	9.0	0.2	3.0	80	27	II	Hidden seepage*
E-97a	8/10/66	8.8	666	4.3	6.8	58	8.6	0.2	2.9	73	25	II	Hidden seepage*
E-99b									0.3				Surface water†
E-104a	6/28/66	8.4	800	1	13.8	93	12	0.4	2.4	82	16	III	Spring*
E-104a	1/1/67	8.0	700	4	9.6	71	12	0.8	0.8	88	6	III	Spring†
E-108e	7/17/66	8.4	500	9	1.3	13	8	0.8	1.5	78	15	I	Auger hole†
E-114d	8/4/66	8.0	200	7	0.4	5	5	0.8	1.6	68	22	I	Auger hole†
E-114d	8/4/66	8.0	100	1	8.3	90	1.4	6.8(?)	1.1	15	12	-	Auger hole†
E-114d	8/4/66	8.0	100	1	7.4	88	1	6.8(?)	0.6	12	7	-	Surface water†
E-117c	7/17/66	8.0	600	6	5.2	46	9	0.8	1.4	80	13	II	Seepage†
E-118a	7/17/66	8.5	700	7	5.5	46	9	2	1.5	72	12	II	Seepage†
E-132a	7/14/66	8.1	600	8	4.8	37	10	0.8	2.0	78	16	II	Spring†
E-141c	8/9/66	8.4	400	7	2.4	26	6	1.2	2.2	64	23	I	Auger hole†
E-141e	8/10/66	8.0	700	9	5.3	37	10	0.8	3.5	70	25	II	Auger hole†
E-141e	8/10/66	8.1	796	7.2	5.4	43	10.3	0.2	2.7	79	20	II	Auger hole*
E-144b	8/9/66	8.0	300	5	0.4	7	4	0.8	0.6	70	11	I	Hidden seepage†
E-147c	8/9/66	8.0	600	18	0	0	14	0.8	2.5	81	14	I	Auger hole†
E-147c	8/1/66	8.0	800	18	0	0	14	0.8	2.4	81	14	I	Auger hole†
E-147c	8/2/66	9.0	200	4	1.1	22	4	0.8	0.3	78	6	-	Surface water†
E-147e	7/18/66	8.2	600	10	1.3	12	10	0.8	0.5	88	4	I	Seepage†
E-181d	8/1/66	8.0	1200	22	3.4	13	11	0.8	13.6	43	54	IV	Auger hole†
E-181d	8/10/66	8.0	900	17	4	19	10	0.8	10	48	48	IV	Auger hole†
E-181d	8/10/66	8.3	1016	10.2	3.5	26	73	0.2	8.5	42	57	IV	Auger hole*
E-196c	8/3/66	8.0	700	16	1.1	6	15	0.8	1.3	88	8	I	Auger hole†
E-202	8/4/66	8.0	500	8	1.6	17	8	0.8	0.8	83	8	I	Seepage†
E-208	8/10/66	8.0	500	10	0.6	6	9	0.8	0.8	85	8	I	Seepage†
E-208	8/10/66	8.6	326	5.0	0.9	15	5.3	0.1	0.55	89	9	I	Seepage*
E-210	8/10/66	8.3	558	5.4	3.4	39	5.0	0.2	4.4	52	46	II	Spring*
E-210	8/10/66	8.4	592	5.0	3.8	43	4.7	0.1	4.6	50	49	II	Spring*
E-211	8/10/66	8.0	700	-	-	-	-	-	-	-	-	-	Spring†

†Analysis by field methods.
*Analysis by Provincial Analyst.

Appendix B. West area: list of chemical analysis* of waters sampled

Obs. Pt. No.	Date sampled	pH	T.D.S. (ppm)	Ca plus Mg (epm)	Na+K (epm)	Na+K % of total cations	HCO_3 $+CO_3$ (epm)	Cl (epm)	SO_4 (epm)	HCO_3 $+CO_3$ % of total anions	SO_4 % of total anions	Type (see Fig. 18)	Remarks
W-1	8/12/66	8.3	546	7.8	1.8	19	8.8	0.5	0.4	91	4	V	Seepage
W-3	8/12/66	7.9	468	7.4	1.6	18	8.4	0.2	0.3	94	3	V	Spring
W-11	8/12/66	8.7	354	3.4	2.6	43	5.3	0.1	0.8	86	13	VI	Auger hole
W-12	8/12/66	8.4	370	3.2	2.8	47	5.9	0.1	0.0	98	0	VI	Spring
W-19	8/13/66	8.1	308	2.8	1.2	30	2.6	0.1	1.4	63	34	V	Auger hole
W-32	8/13/66	7.7	354	6.0	1.2	17	6.2	0.3	0.6	88	8	V	Spring
W-33	8/13/66	8.6	260	4.3	0.3	7	4.2	0.1	0.4	89	9	V	Spring
W-44b	8/15/66	8.3	446	6.7	1.5	18	6.8	0.3	1.1	84	13	V	Spring
W-55	8/17/66	7.8	440	5.5	2.2	29	7.0	0.2	0.9	86	11	V	Auger hole
W-60	8/17/66	9.1	1668	1.4	17.6	87	4.2	0.2	15.9	20	80	VIII	Auger hole
W-67	8/18/66	8.5	3672	3.4	51.2	86	24.3	0.1	26.8	47	52	VIII	Auger hole
W-67a	9/12/66	9.0	9838	13.8	136.6	90	42.0	0.1	110.0	28	72	VIII	Auger hole
W-80	8/23/66	8.9	410	4.8	1.3	21	4.6	0.2	1.3	75	21	V	Auger hole
W-100	8/31/66	7.9	1040	12.6	2.1	14	8.2	0.1	7.5	52	48	VII	Seepage
W-113	9/2/66	8.7	400	1.9	4.8	72	6.2	0.1	0.3	94	5	VI	Spring
W-117	9/3/66	7.6	360	4.1	1.1	21	3.0	0.1	2.1	57	40	VII	Surface water from ditch
W-117	9/3/66	7.6	1584	19.9	1.4	7	9.0	0.1	13.6	40	60	VII	Auger hole to west
W-117	9/3/66	7.6	3247	40.2	0.0	0	7.6	0.1	35.1	18	82	VII	Auger hole to east
W-120	9/4/66	8.2	310	4.6	0.7	13	4.5	0.1	0.9	82	16	V	Seepage
W-121	9/4/66	8.3	320	4.3	1.9	31	5.4	0.1	0.9	85	14	V	Spring
W-122	9/5/66	8.2	390	4.4	1.5	25	4.6	0.1	1.5	74	24	V	Seepage
W-140	1/1/67	8.3	468	4.3	3.2	44	7.1	0.1	0.2	96	3	VI	Spring
W-150	9/12/66	8.5	426	5.6	1.4	20	6.3	0.1	0.7	89	10	V	Spring
W-151	9/12/66	8.0	442	5.1	3.0	37	7.7	0.2	0.3	94	4	VI	Spring
W-152	9/12/66	7.8	386	6.3	1.2	16	7.2	0.2	0.1	96	1	V	Spring

*Analyses by Provincial Analyst

Appendix B. Total dissolved solids of surface waters obtained throughout field season

Obs. Pt. No.	Date sampled	T.D.S. (ppm)	Obs. Pt. No.	Date sampled	T.D.S. (ppm)
E-6	6/15/66	1300	E-92d	6/23/66	400
E-9	6/15/66	900	E-93f	6/25/66	800
E-19	6/15/66	100	E-95e	6/25/66	500
E-24	6/16/66	200	E-99b	6/27/66	100
E-25	6/16/66	400	E-132d	7/14/66	300
E-26	6/16/66	800	E-147c	8/2/66	300
E-43	6/16/66	500		8/3/66	290
E-60	6/18/66	500		8/4/66	250
E-83	6/20/66	200		8/10/66	290
E-90b	6/23/66	800	E-185		900
E-91d	6/23/66	300		9/24/66	1300
E-91c	6/24/66	300	E-192	8/2/66	400

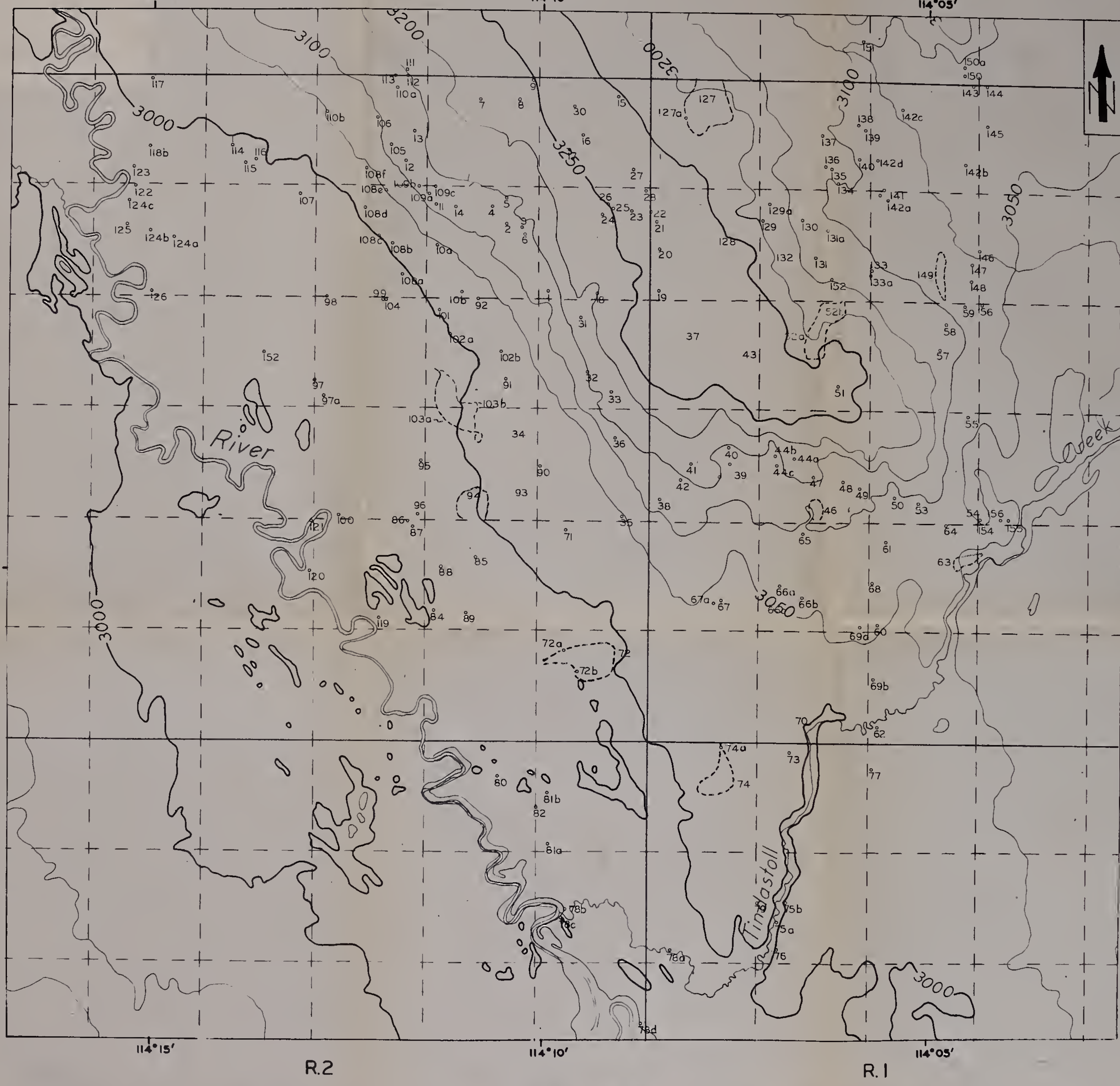
Conductivities of surface waters in micromho/cm on September 24, 1966

Point of sampling	Corresponding obs. pt. no.	Conductivity in μ mho/cm	Point of sampling	Corresponding obs. pt. no.	Conductivity in μ mho/cm
A	E-185	1300	M	-	140
B	-	800	N	E-66	900
C	-	1000	O	E-153d	600
D	-	1100	P	E-173	750
E	-	850	Q	-	750
F	-	750	R	E-192	900
G	-	700	S	E-186	2000
H	E-163a	650	T	E-187	850
I	-	200	U	-	1100
J	-	440	V	-	480
K	E-123	1200	W	-	220
L	E-132d	460			

Map accompanying

Appendix A

WEST AREA



West Area

LEGEND

Observation point and number 66c
Traverse and number 127

SCALE 1:50,000

1000 0 1000 2000 3000 4000 meters

1 0 1 mile

CONTOUR INTERVAL 50 FEET

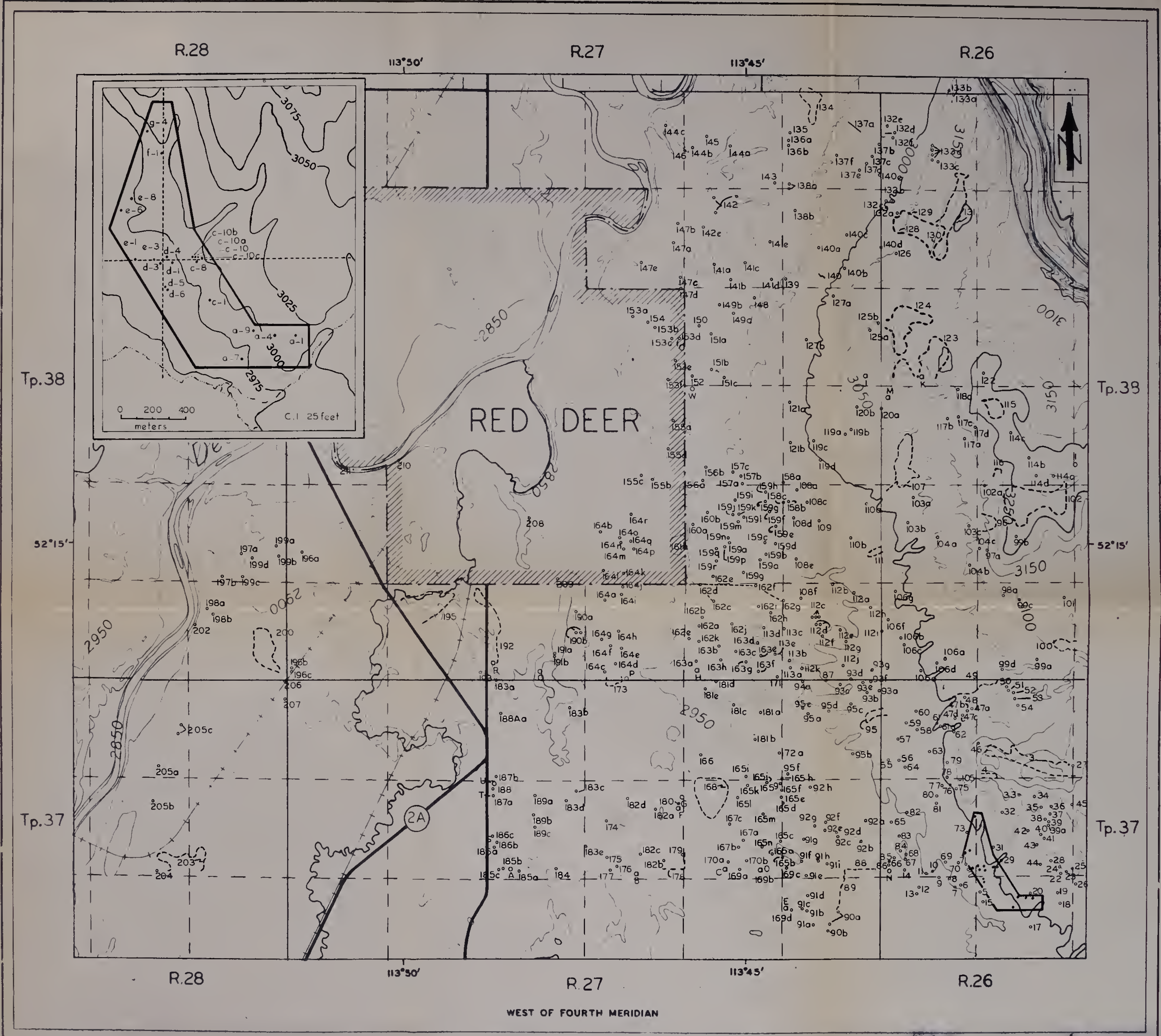
REFERENCE

Township line.........................
Section line ....
Surface contours:
elevation 3150

Map accompanying

Appendix A

EAST AREA



East Area

LEGEND

Observation point and number . . . . °47b
Traverse and number 168
Surface water conductivity September, 1966. °Q
Inset E-1 area . . . .

SCALE 1:50,000

1000 0 1000 2000 3000 4000 meters

1 0 1 mile

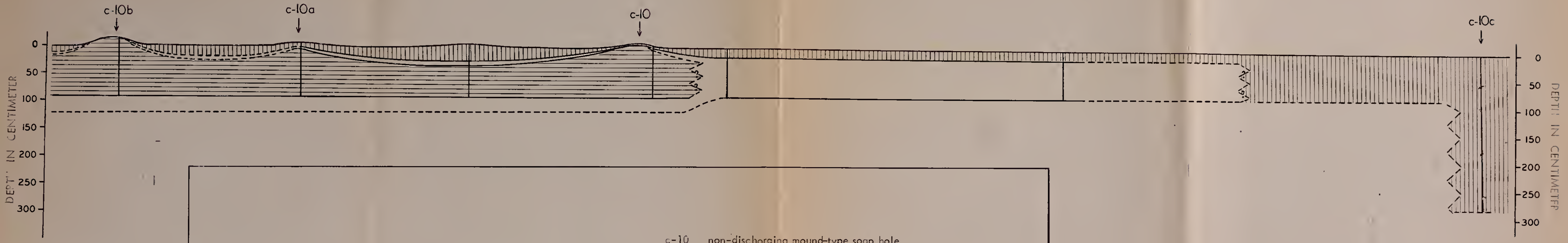
CONTOUR INTERVAL 50 FEET

REFERENCE

Township line . . . .
Section line . . . .
Highway . . . . (2)
Railway . . . .
Surface contours:
elevation 3150

Figure 10. Diagrammatic cross section showing the distribution of type A, type B and type C material associated with soap holes E-1 (c-10, c-10a and c-10b)

Figure 10. Diagrammatic cross section showing the distribution of type A, type B and type C material associated with soap holes E-1 (c-10, c-10a and c-10b)



c-10	non-discharging mound-type soap hole
c-10a	mound-type soap hole discharging water
c-10b	mound-type soap hole discharging viscous fluid (see Plate VI)
c-10c	flowing auger hole
|	auger hole

Type A material - viscous fluid (see Plate [illegible])

Type B material - wet sticky material which is pliable like modelling clay (cannot resist deformation under pressures up to approximately 5 kg/cm^2)

Type C material - extremely hard, dry, infertile material

Horizontal scale	1:100
Vertical scale	1:50
Vertical exaggeration	2

Reference point: Surface elevation of c-10 - 2,8?2 ft.